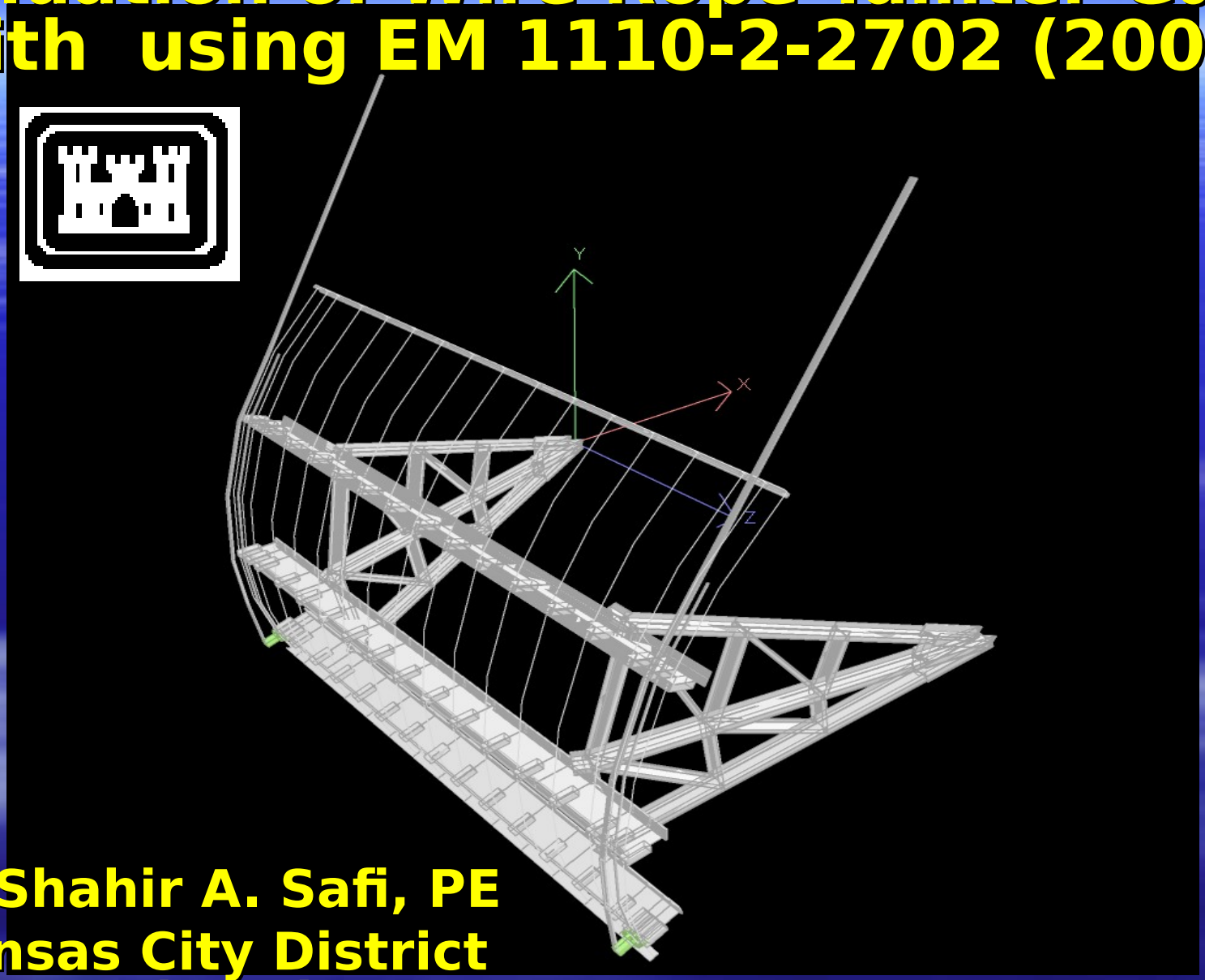
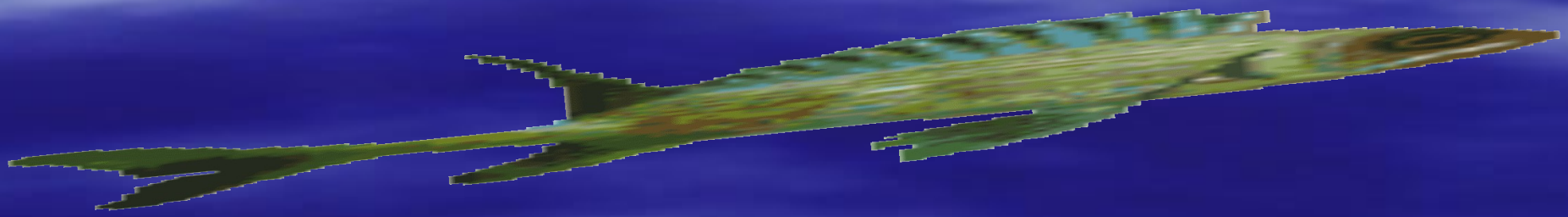
Evaluation of Wire Rope Tainter Gates with using EM 1110-2-2702 (2000)



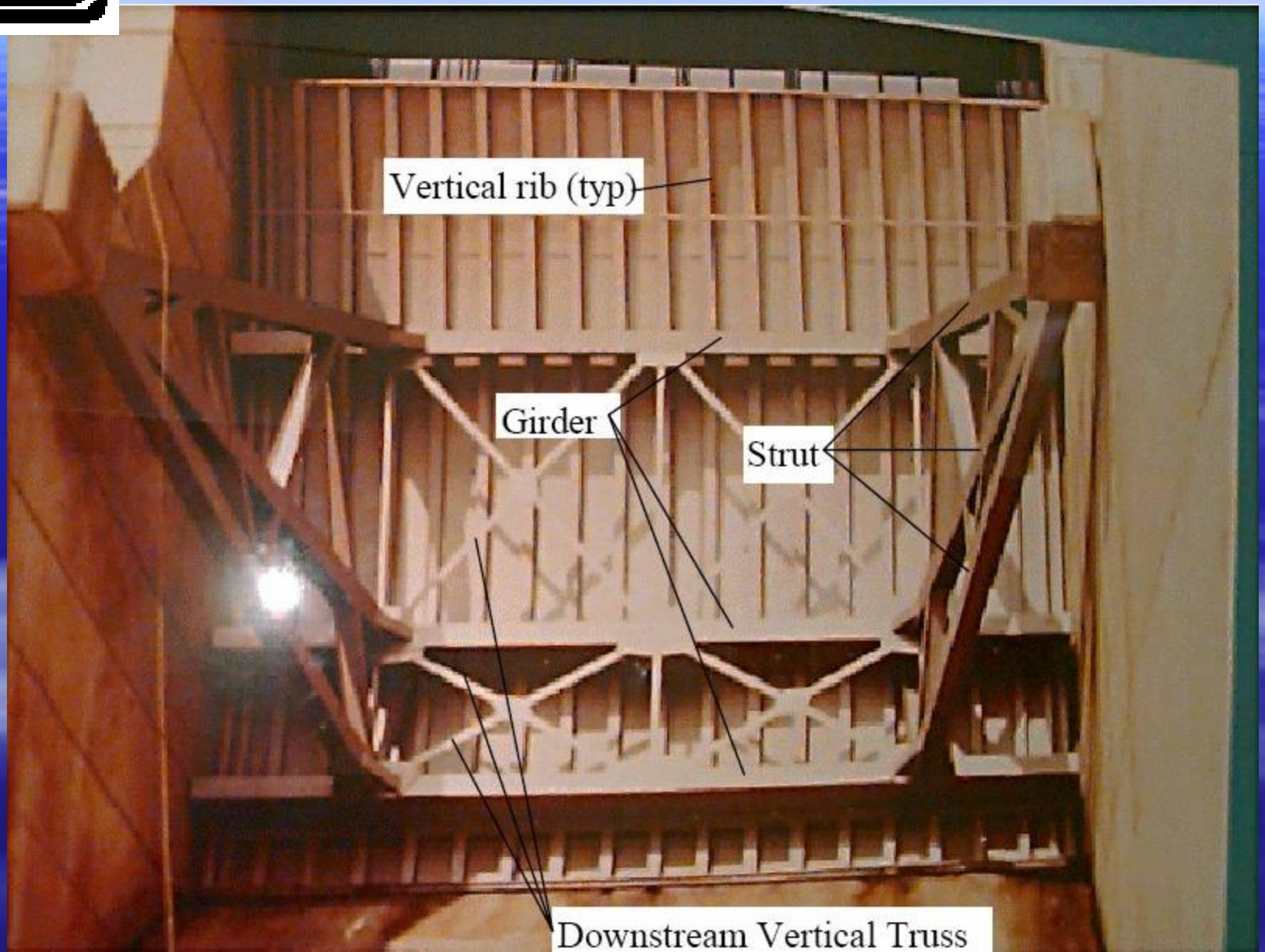
By: Shahir A. Safi, PE
Kansas City District
Corps of Engineers

Presentation Outline

- Tainter Gate Terminology
- Generating 3D centerline model in Micro Station for export to STAAD
- Building the 3D Frame Model in STAAD
- LRFD Code of Tainter Gate Elements



Tainter Gate Terminology

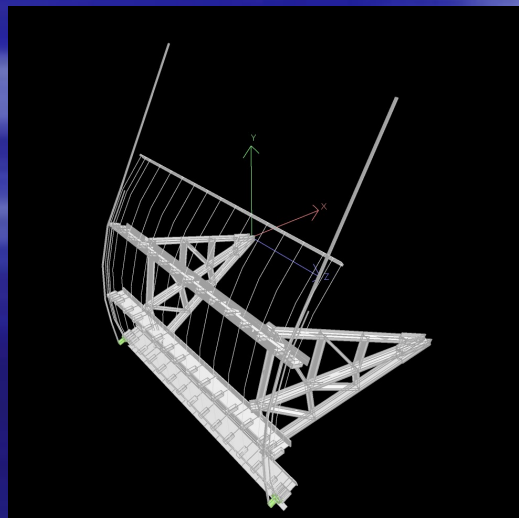


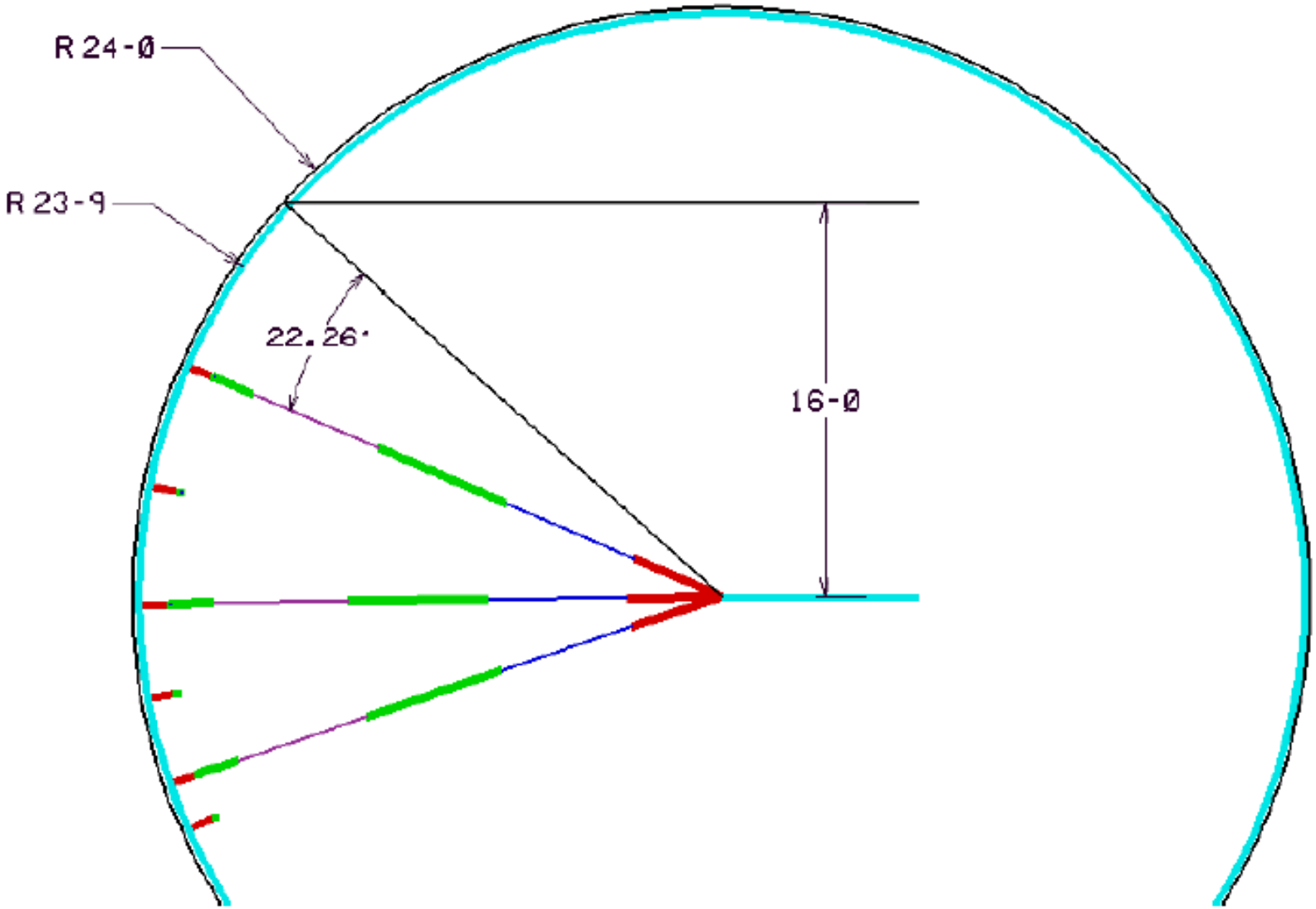
3D Centerline Model Drawn in Micro Station

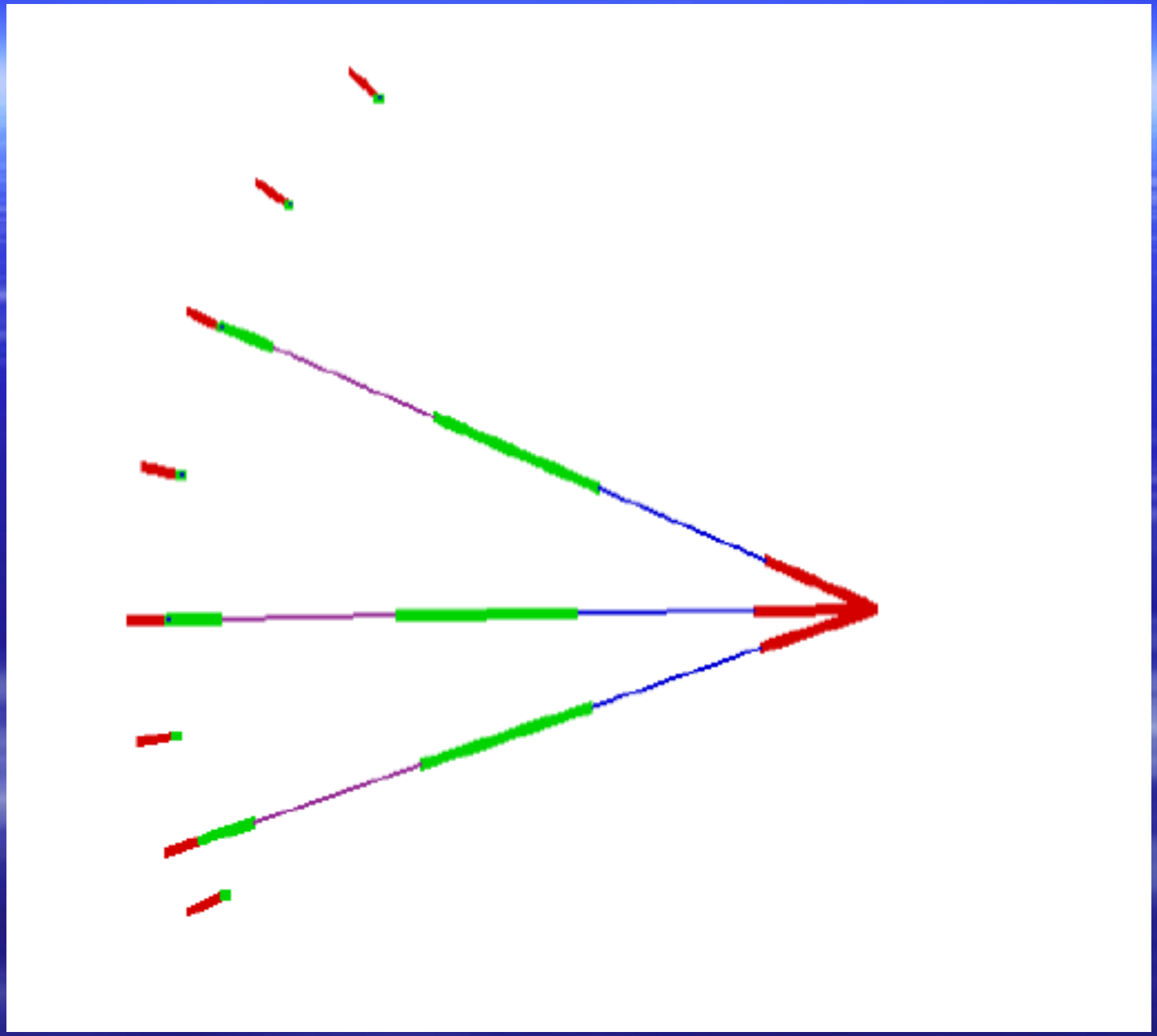
-Dimensions are taken from Record Drawings

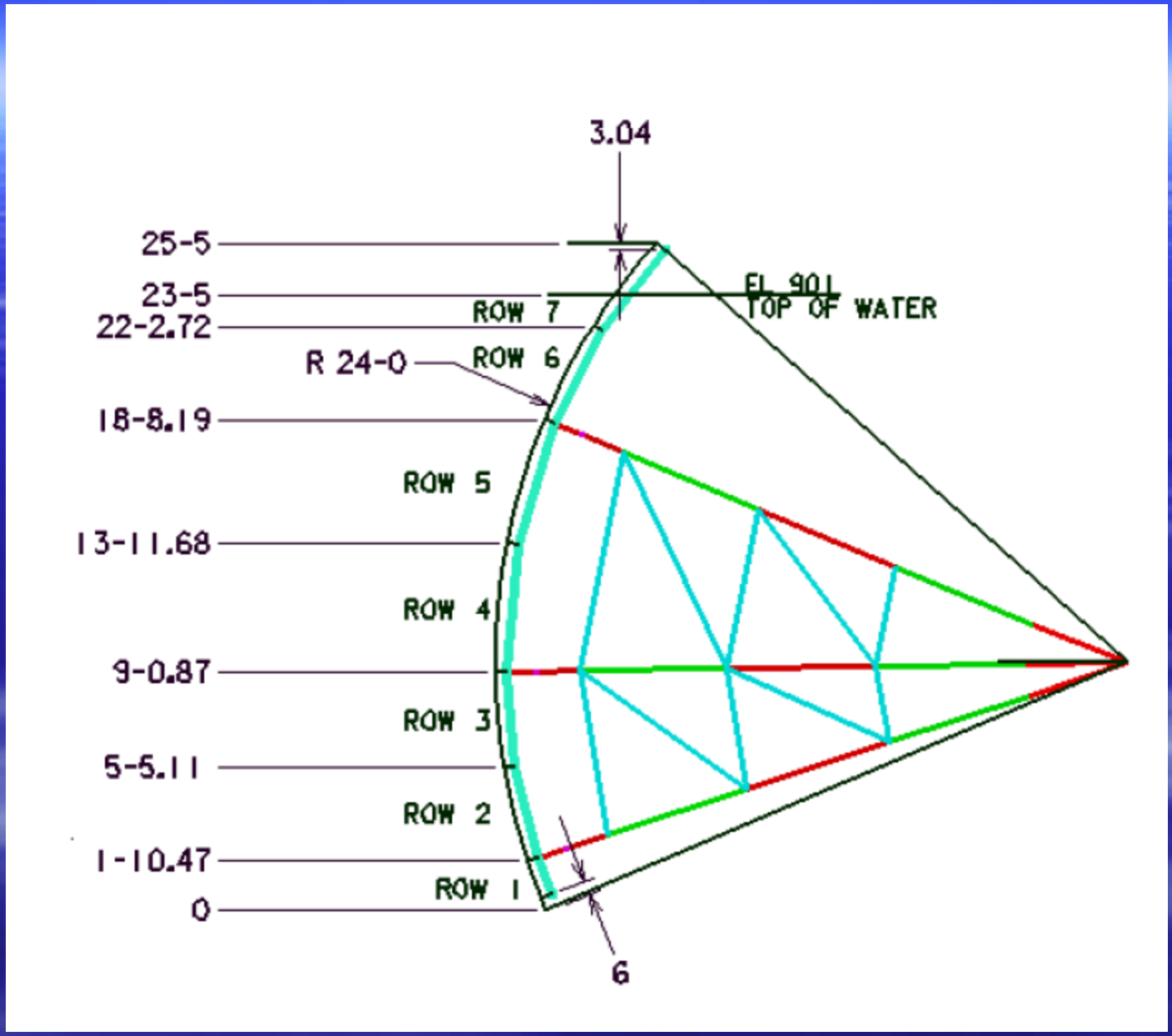
-Completed MicroStation model is then saved as a DXF file

-DXF file imported into STAAD

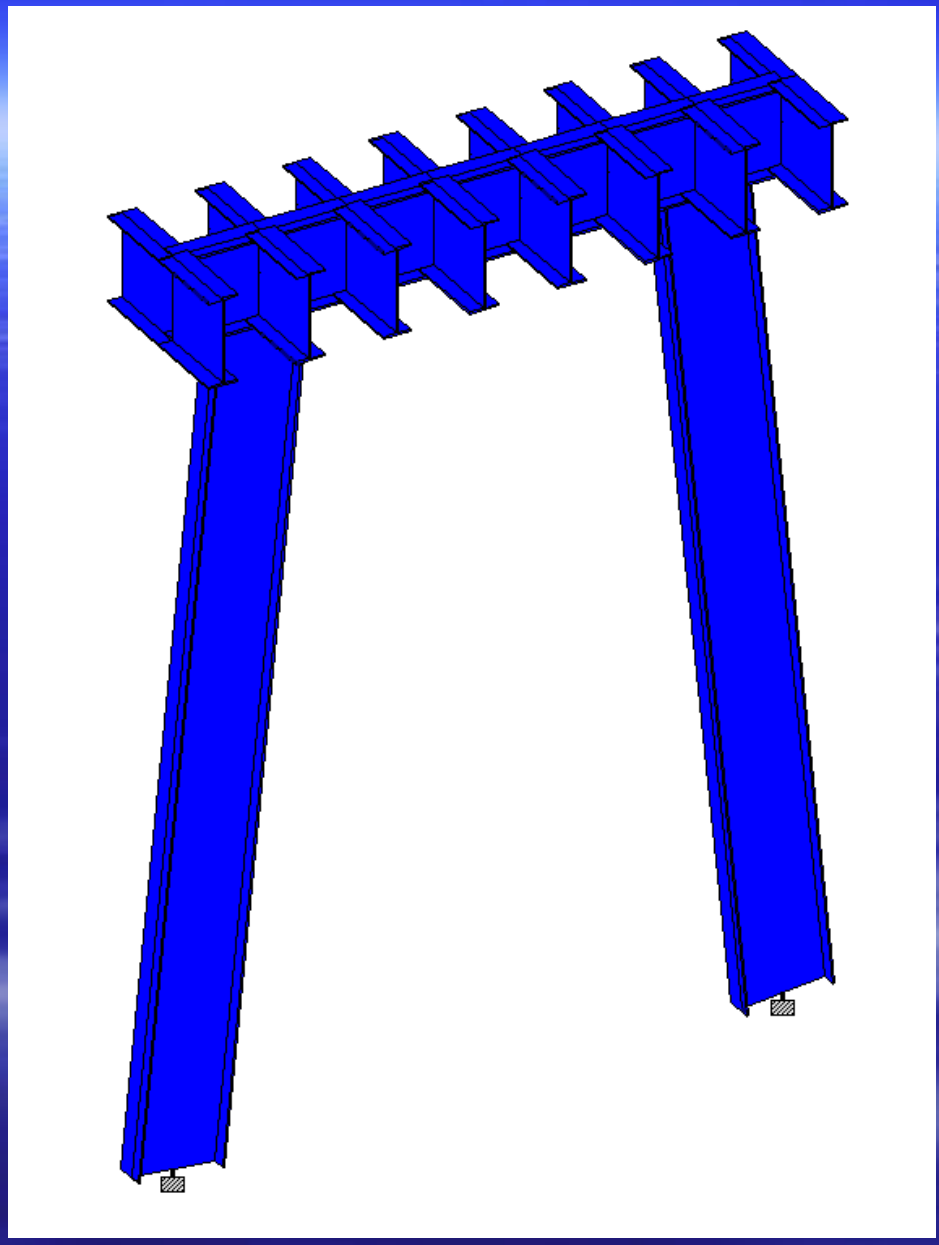



R 24-Ø
R 23-9
22.26°
16-Ø

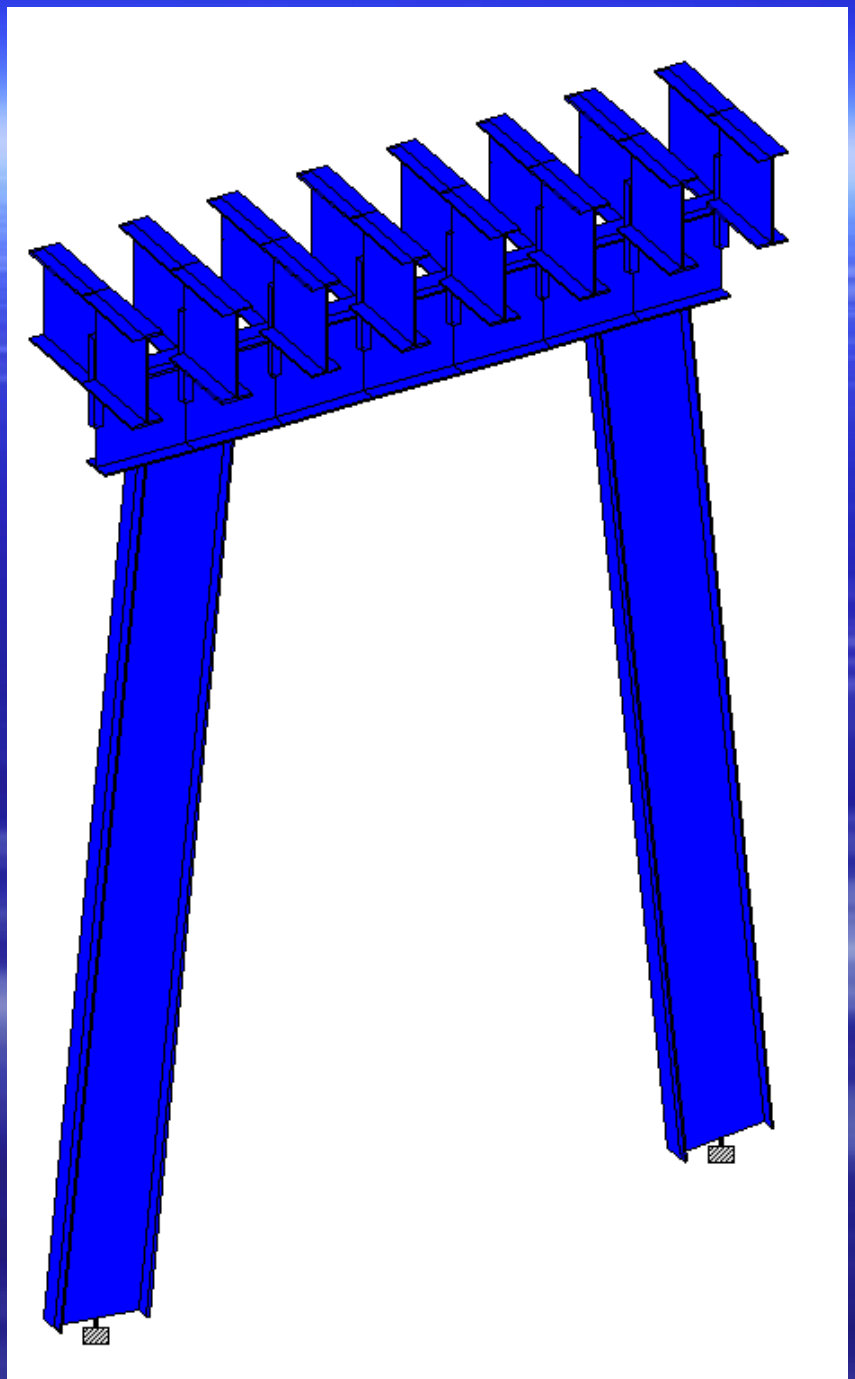


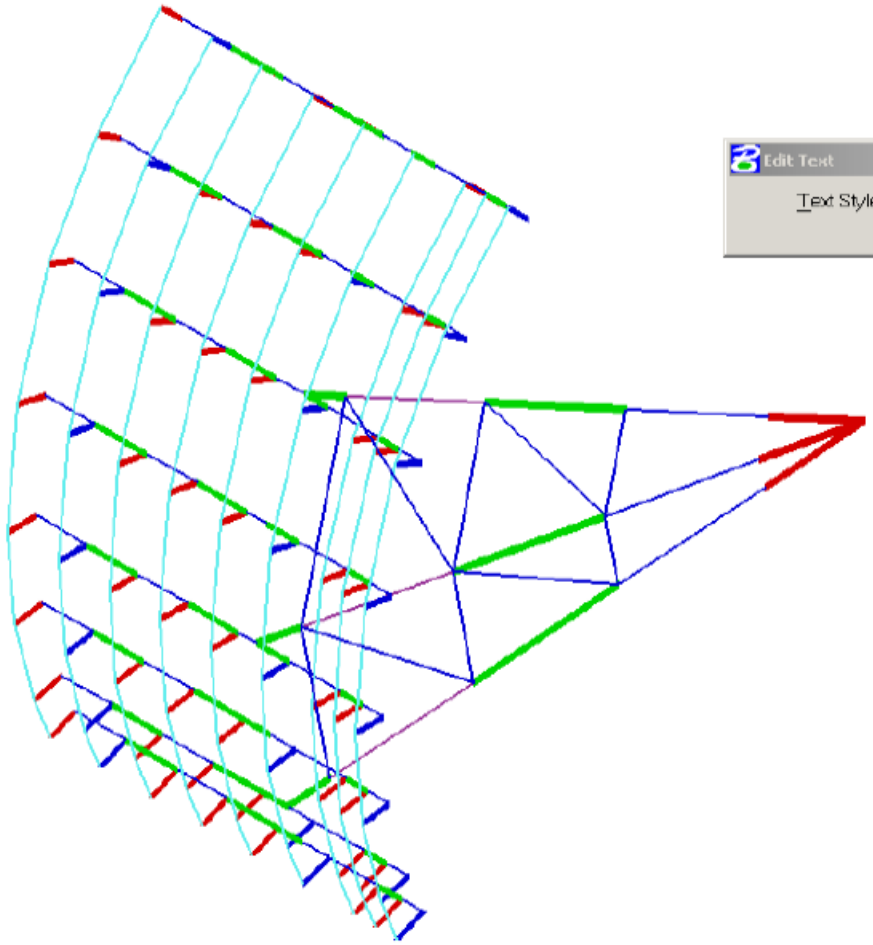

3.04
25-5
23-5
22-2.72
R 24-0
18-8.19
13-11.68
9-0.87
5-5.11
1-10.47
0
ROW 7
ROW 6
ROW 5
ROW 4
ROW 3
ROW 2
ROW 1
EL 901
TOP OF WATER
6

Horizontal Girder and Vertical Rib modeled with on same center-

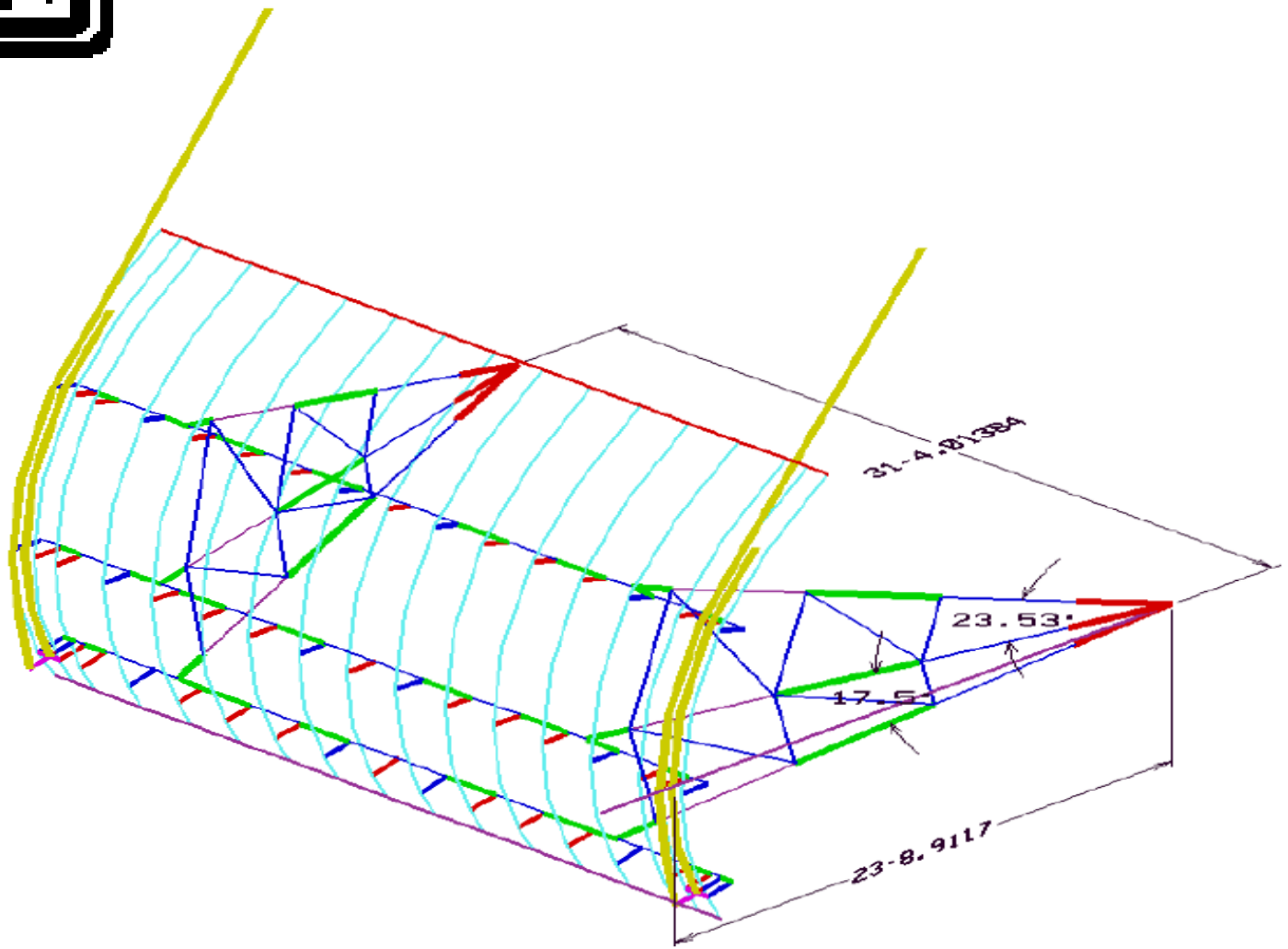


Horizontal Girder and Vertical Rib modeled with eccentric



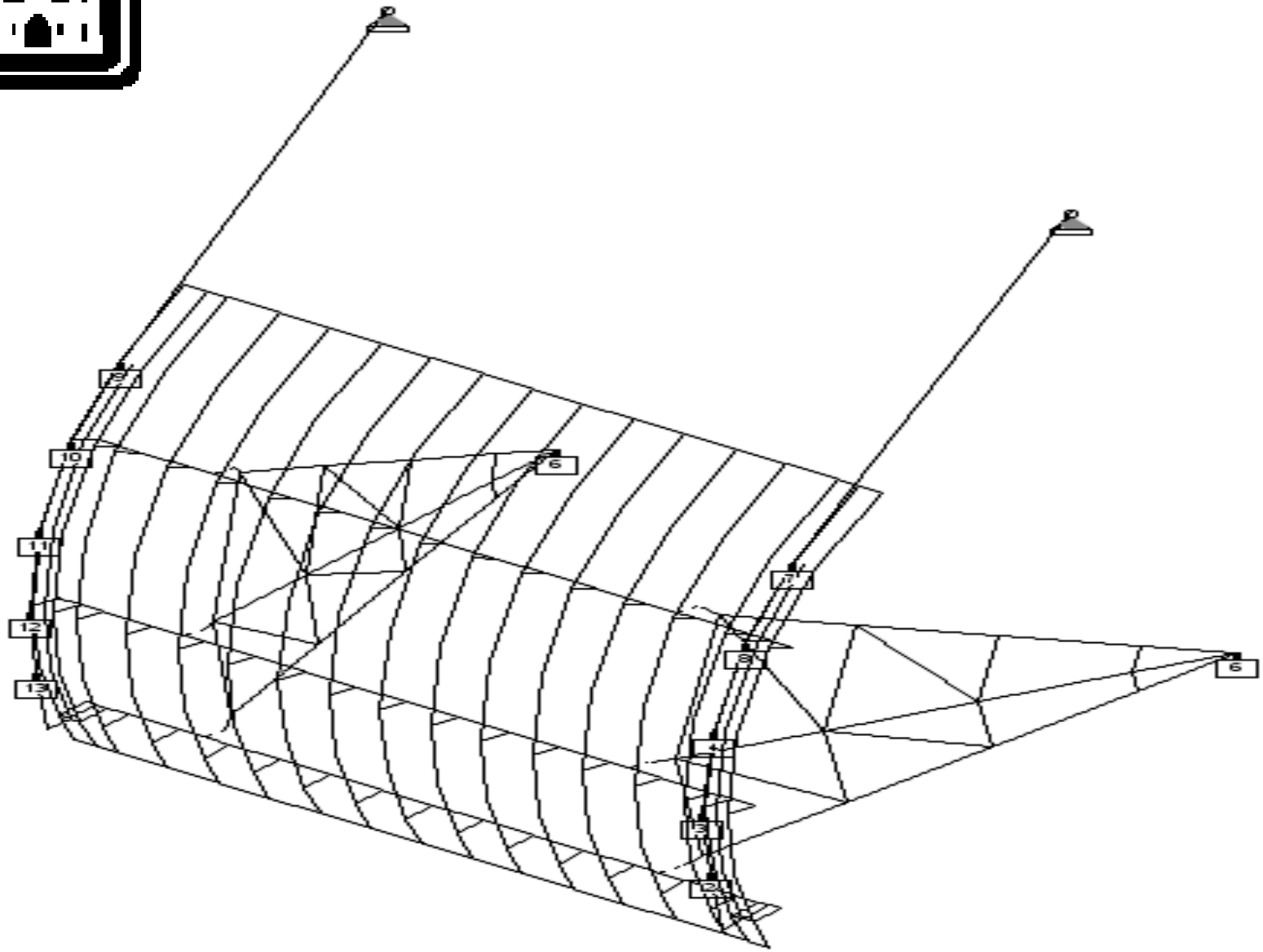


The model with vertical ribs, and the strut braces look as shown.



The final midline model file is shown above with the critical dimension matching the dimensions shown in the record drawing.

MICROSTATION MODEL EXPORTED TO STAAD

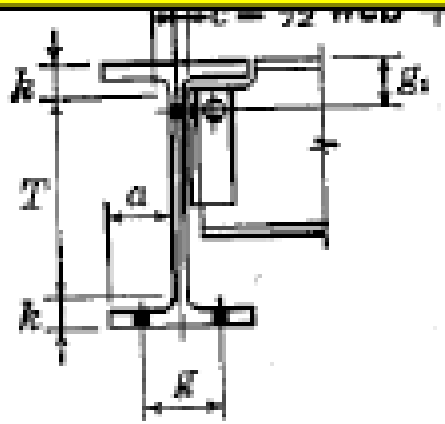


ASSIGNMENT OF SECTION PROPERTIES

TOP (24WF68) MIDDLE AND BOTTOM (24WF84) HORIZONTAL GIRDER GEOMETRIC AND MECHANIC PROPERTIES FROM AISC 6TH EDITION - PER DOUG KISH'S EMAIL ATTACHMENT

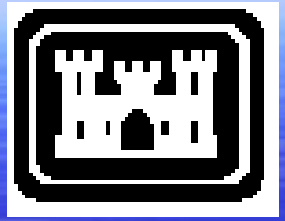
WF SHAPES

Dimensions for detailing



Nominal Size	Weight per Foot	Depth	Flange		Web		Distance						Usual Gage g
			Width	Thick-ness	Thick-ness	Half Thick-ness	a	T	k	k_1	g_1	c	
In.	Lb.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.	In.
24×9	94	24¼	9	⅞	½	¼	4¼	21⅜	1⁷⁄₁₆	1³⁄₁₆	3	⁵⁄₁₆	5½
	84	24⅛	9	¾	½	¼	4¼	21⅜	1⅜	1³⁄₁₆	2¾	⁵⁄₁₆	5½
	76	23⅞	9	¹¹⁄₁₆	⁷⁄₁₆	¼	4¼	21⅜	1⅜	1³⁄₁₆	2¾	⁵⁄₁₆	5½
	68	23¾	9	⁹⁄₁₆	⁷⁄₁₆	³⁄₁₆	4¼	21⅜	1³⁄₁₆	¾	2½	⅛	5½

ASSIGNMENT OF SECTION PROPERTIES



AISC Search Utility for Structural Steel Shapes. v13.

File Help

Library	Type
LRFD2	W
LRFD1	WF
ASD9	STWF
ASD8	LWF
ASD7	B
ASD6	JR
ASD5	I
HISTORIC	M

Quick Find

- WF24 x 12
- WF24 x 12
- WF24 x 12
- WF24 x 9
- WF24 x 9
- WF24 x 9
- WF24 x 9

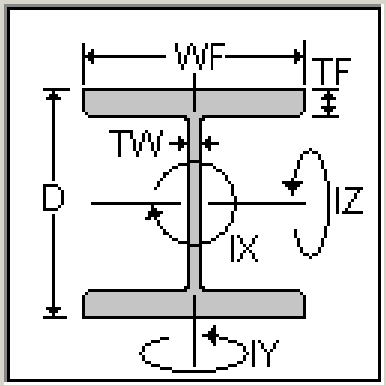
Section #: 21 of 146

DESIGNATION: WF24 x 9

$W=$	68	$A=$	20	$d=$	23.71
$t_w=$	0.416	$b_f=$	8.961	$t_f=$	0.582
$I_x=$	1814.5	$S_x=$	153.1	$r_x=$	9.53
$I_y=$	63.8	$S_y=$	14.2	$r_y=$	1.79
$\frac{d}{A_f}=$	4.55				

ASSIGNMENT OF SECTION PROPERTIES

Wide Flange



Section Name : 24WF68

Cross Section Area (Ax) : 20 in²

Inertia about local z (Iz) : 1814.5 in4

Inertia about local y (Iy) : 63.8 in4

D: 23.75 in

TF: 0.563 in

WF: 9 in

TW: 0.438 in

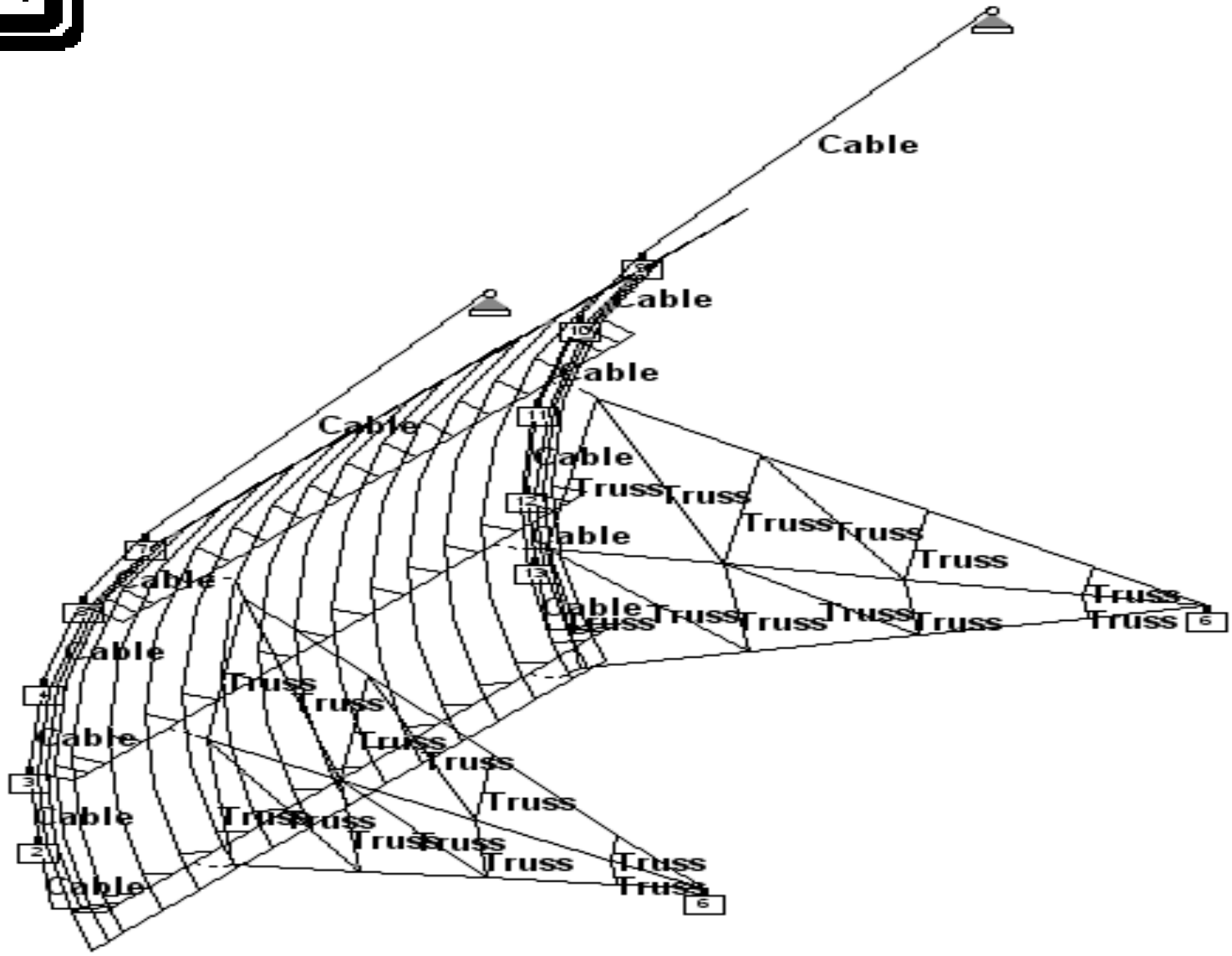
Torsional Constant (Ix) : 1.7044 in4

Shear Area in Y (Ay) : 10.4025 in²

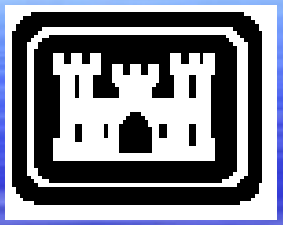
Shear Area in Z (Az) : 6.756 in²

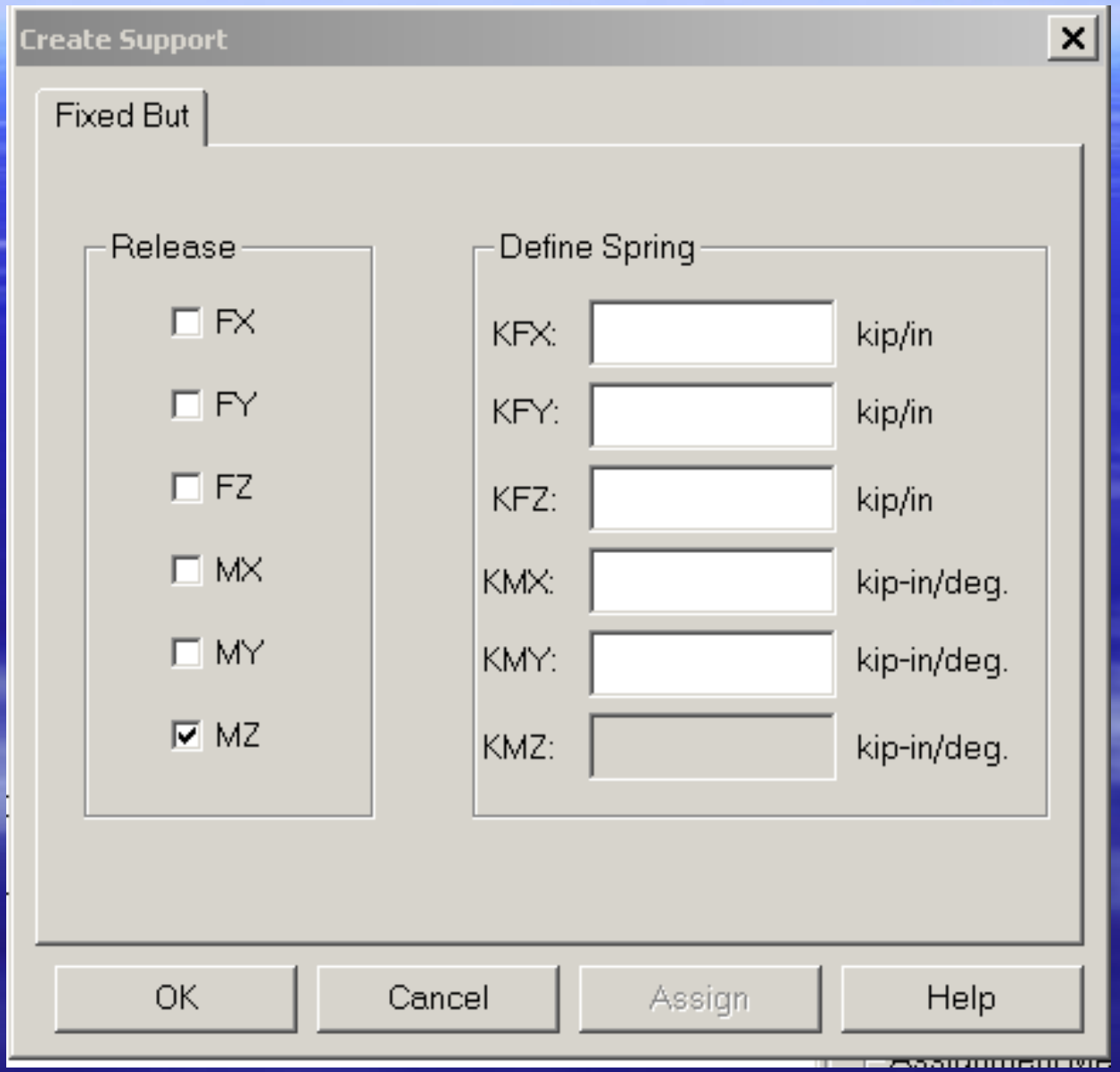
OK | Cancel | Calculate

SPECIFICATIONS OF STRUCTURE MEMBERS


Cable
Cable
Cable
Cable
Cable
Cable
Truss
Truss
Truss

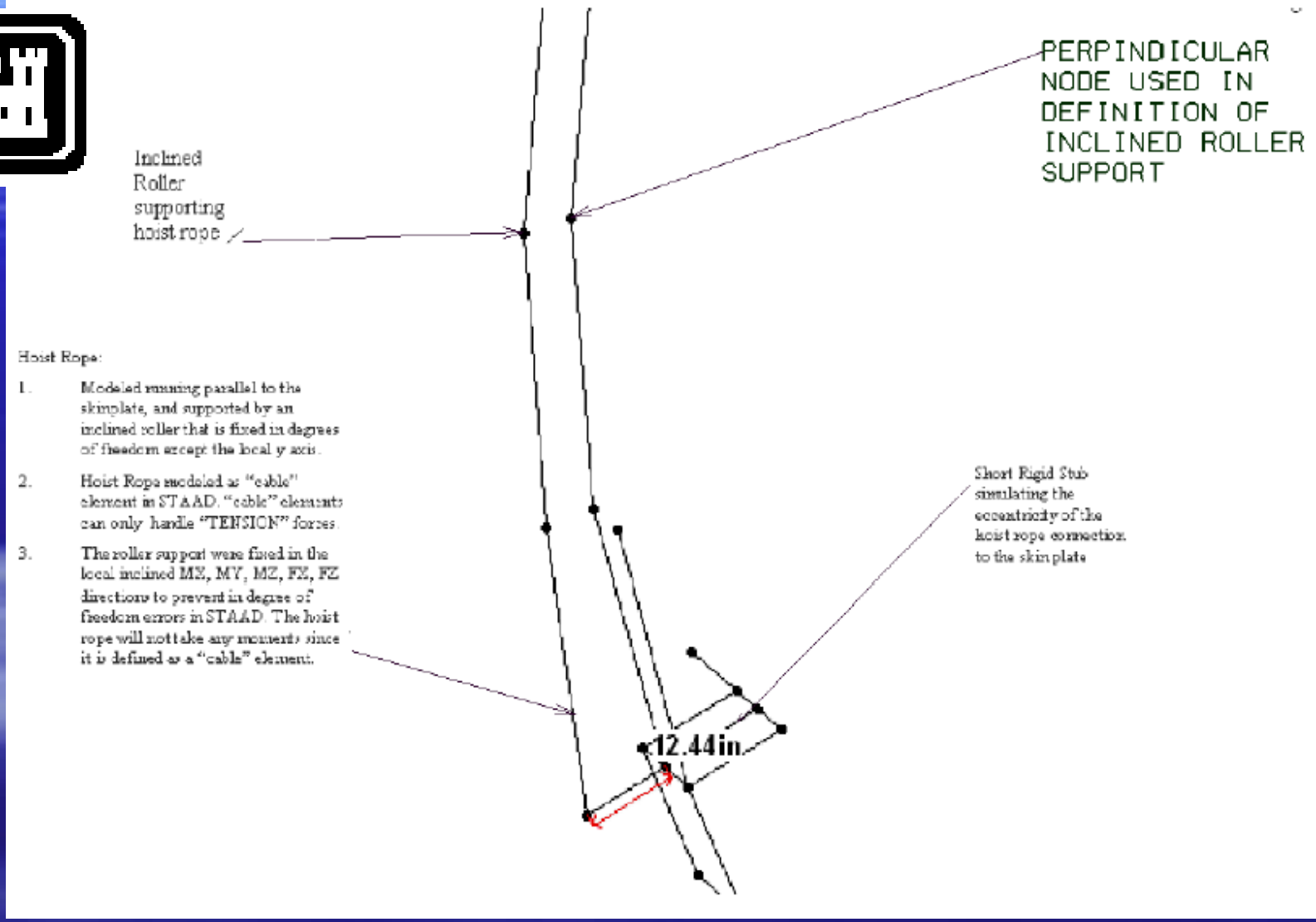
TRUNNION SUPPORT CONDITION



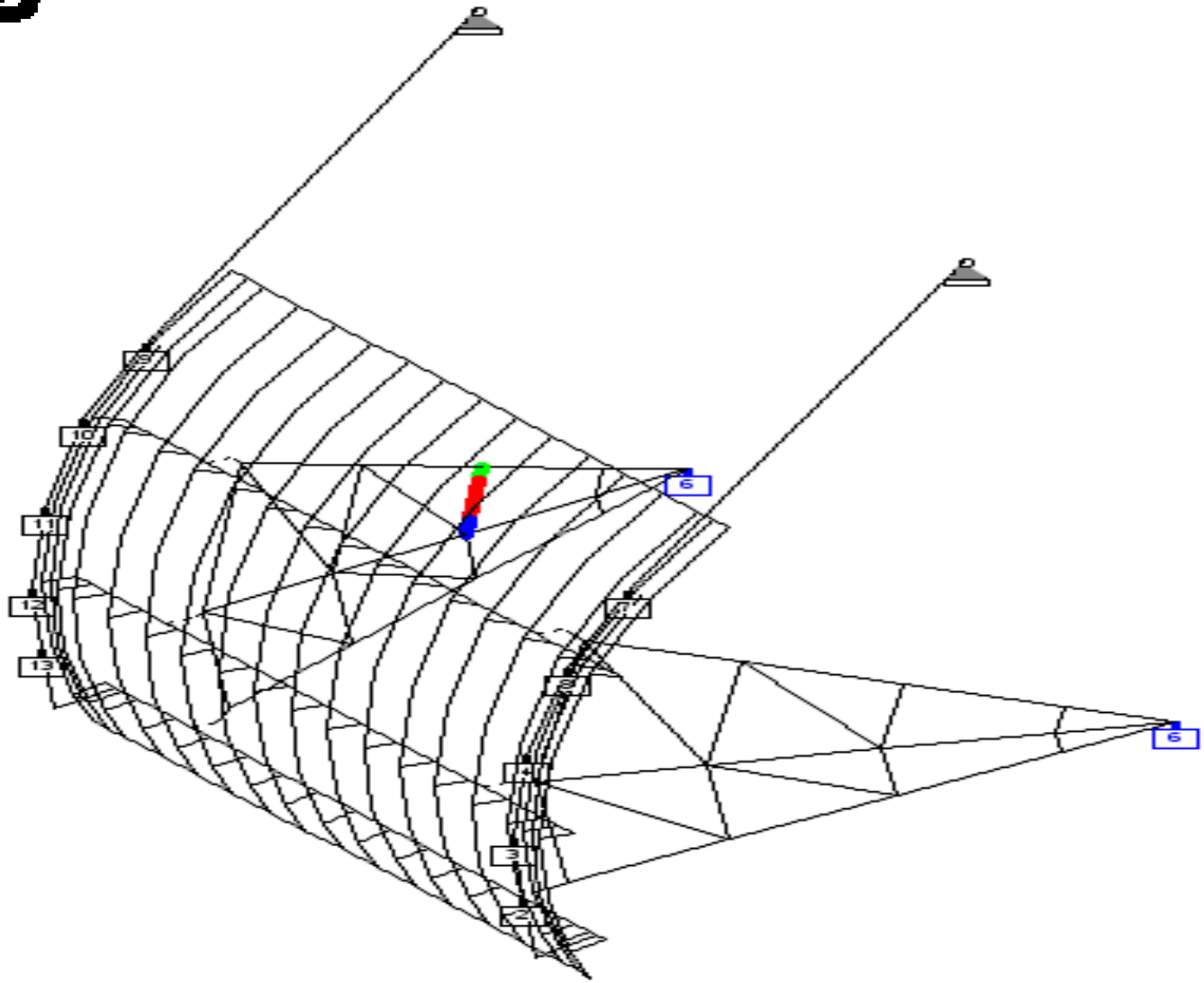


WIRE ROPE AGAINST SKINPLATE

Support Conditions: 1. Bottom Wire Rope Support Conditions (Only):

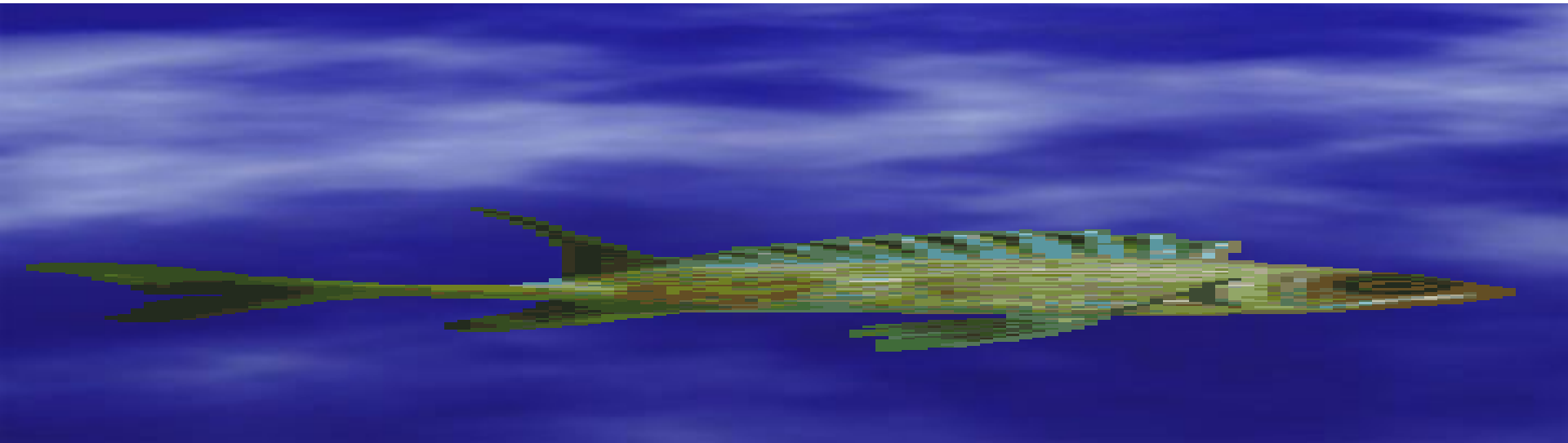

PERPINDICULAR NODE USED IN DEFINITION OF INCLINED ROLLER SUPPORT
Inclined Roller supporting hoist rope
Hoist Rope:
1. Modeled running parallel to the skinplate, and supported by an inclined roller that is fixed in degrees of freedom except the local y axis.
2. Hoist Rope modeled as "cable" element in STAAD. "cable" elements can only handle "TENSION" forces.
3. The roller support were fixed in the local inclined MX, MY, MZ, FX, FZ directions to prevent in degree of freedom errors in STAAD. The hoist rope will not take any moments since it is defined as a "cable" element.
Short Rigid Stub simulating the eccentricity of the hoist rope connection to the skin plate
12.44in

WIRE ROPE DRUM ASSEMBLY SUPPORT MODELED AS PIN



EM LOAD 1 – GATE SITTING ON THE SILL

$$1.4 \cdot H_1 + 1.2 \cdot D + 1.6 \cdot (C + M) + 1.2 \cdot Q_2$$



EM LOAD 1 – GATE SITTING ON THE SILL

In the above Load Case 1 the acronyms are defined as follows:

H_1	For our analysis it is the hydrostatic Load to 2 ft below the top of gate. See Hydrostatic Load calcs below for more details.
H_2	Operating pool condition, not applicable for the scope of this analysis. Therefore ignored
D	The tainter gate self dead load
C & M	The ice and mud load which is not used in this analysis.
Q_2 & Q_1	The hydraulic cylinder load which is not applicable to this analysis since we have wire rope hoists at Alum Creek.

EM LOAD 1 – GATE SITTING ON THE SILL

EM Load Case 1 used in this analysis:

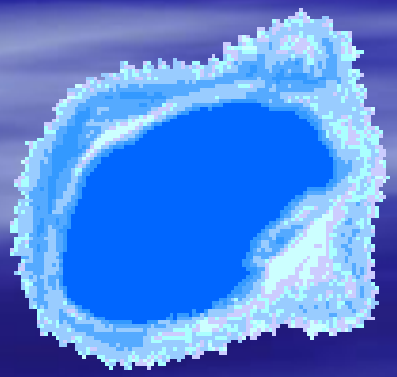
Based on the above discussion the EM load case 1 for this analysis is:

$$1.4 \times H_1 + 1.2 \times D$$

EM LOAD 2 – GATE LIFTING OFF SILL WITH TWO HOIST CABLES

$$1.4 \cdot H_1 + 1.2 \cdot D + 1.6(C + M) + 1.2 \cdot Q_2$$

$$1.4 \cdot H_2 + 1.2 \cdot D + 1.6(C + M) + 1.4F_S + 1.0F_t + 1.2\left(W_A \text{ or } \cdot k_1 \cdot I\right)$$



EM LOAD 2 – GATE LIFTING OFF SILL WITH TWO HOIST CABLES

In the above Load Case 2 the acronyms are defined as follows:

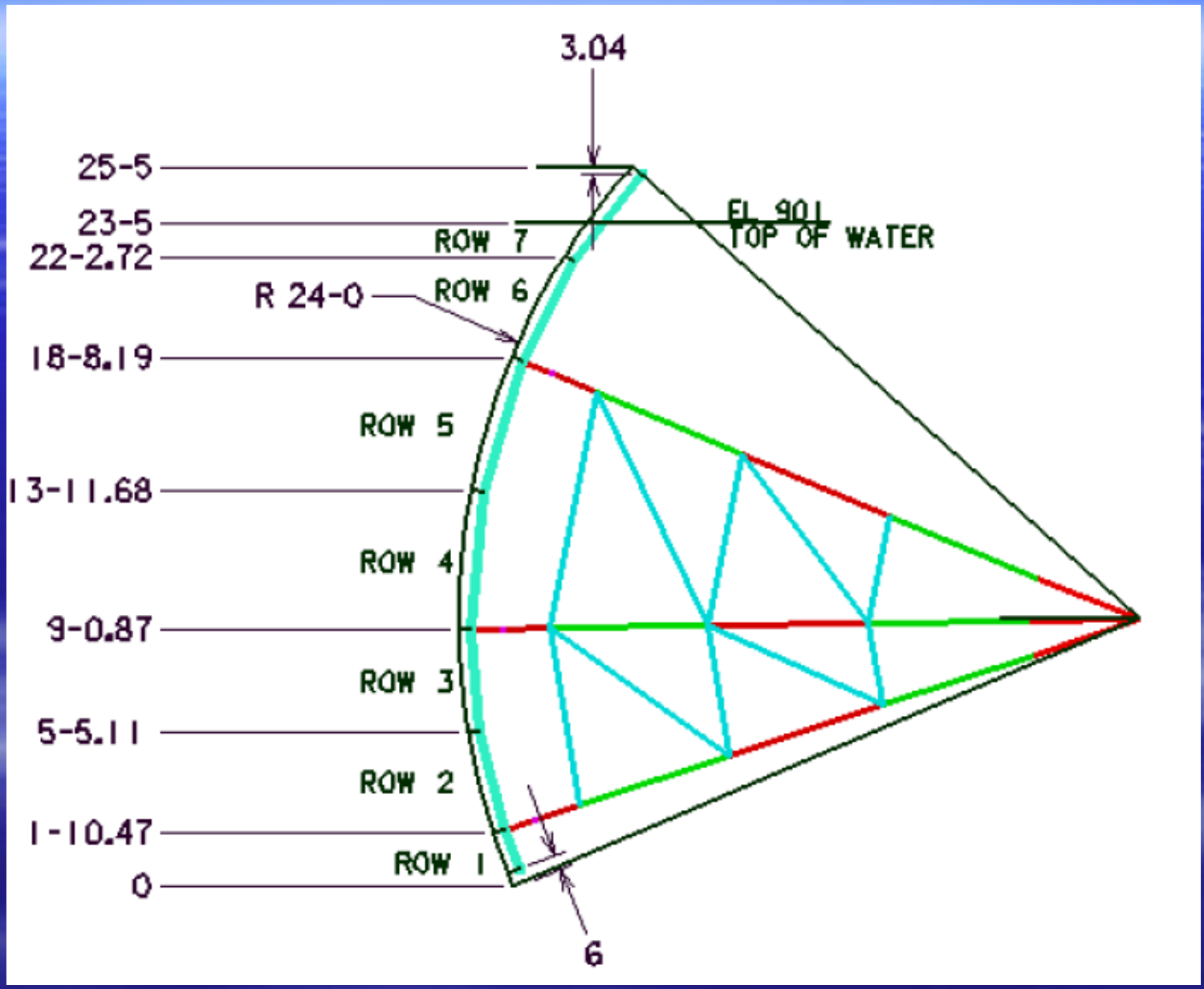
F_s	Side Seal force caused by the J-bulb rubbing against the pier wall. See appropriate section below for details and calculations.
F_t	Trunnion Friction load, see Sections below for detailed discussion.
W_A	Wave loads behind tainter gate. Ignored for this analysis per John Jeager and Doug Kish of Hunington District.

EM LOAD 2 – GATE LIFTING OFF SILL WITH TWO HOIST CABLES

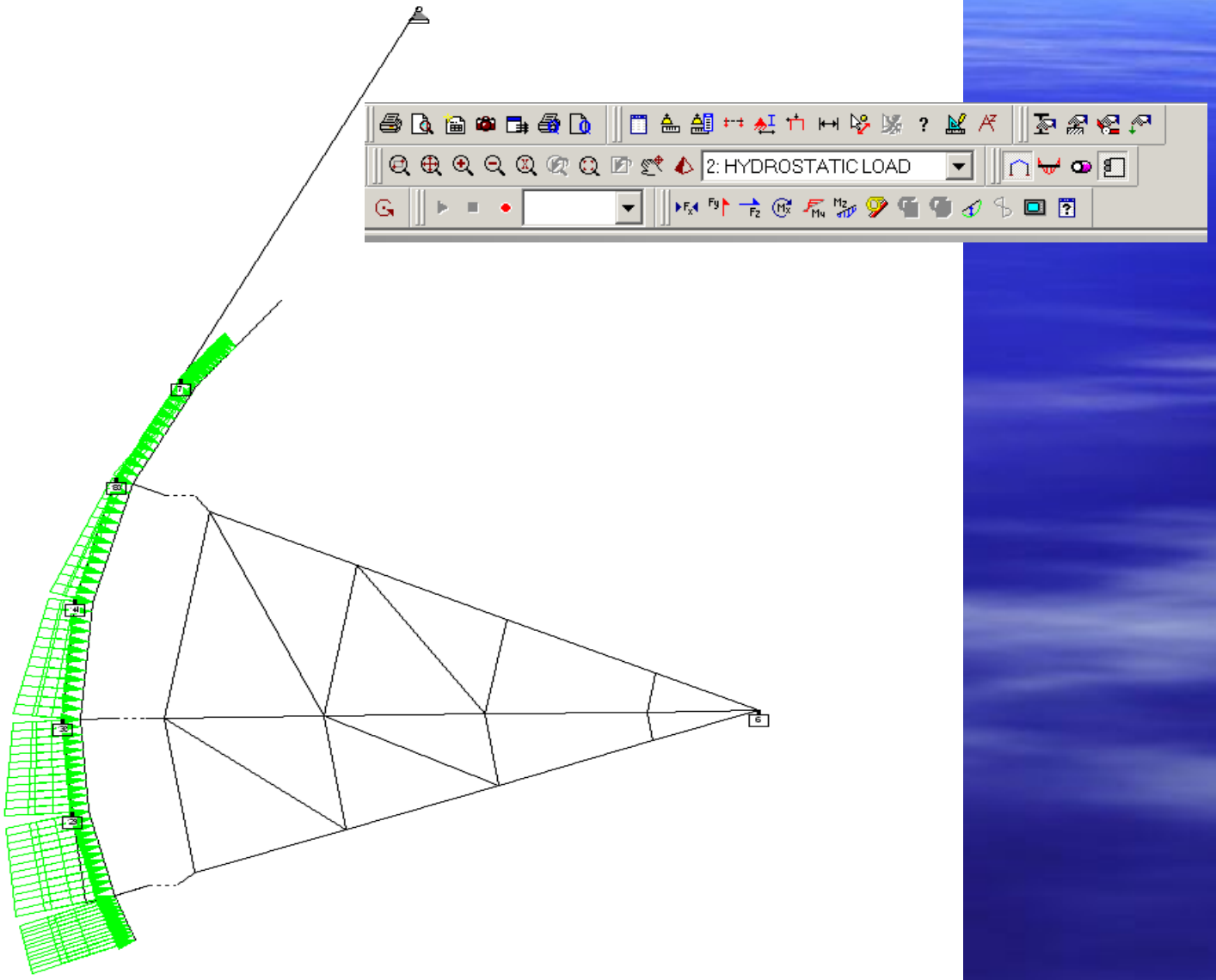
EM Load Case 2 used in this analysis:

$$1.4H_l + 1.2D + 1.4F_s + 1.0F_t$$

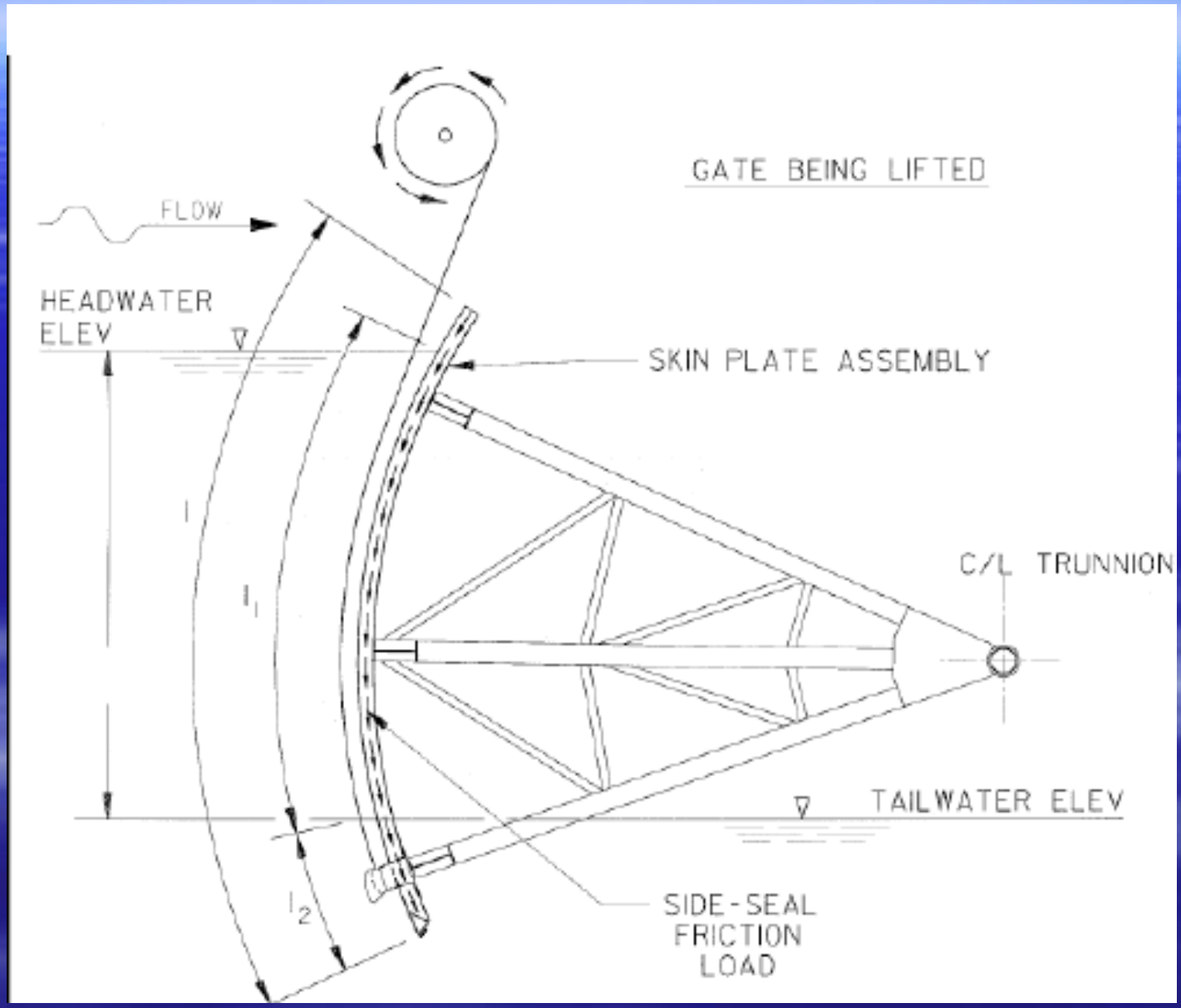
HYDROSTATIC LOAD



HYDROSTATIC LOAD



SIDE SEAL LOAD:



EM FORMULA FOR ESTIMATING THE SIDE SEAL LOAD:

HDROSTATIC HEAD AGAINST J-BUL

$$F_s = \mu_s S l + \mu_s \gamma_w \frac{d}{2}\left(l_1 \frac{h}{2} + h\, l_2 \right)$$

J-BULB RUBB AGAINST PIER

SIDE SEAL LOAD:

J -Bulb Rubbing Against Pier Side Seal Load:

In the STAAD model this Load will be applied over the entire side seal length.

$$Rubbing\_J\_Bulb := \mu_{side\_seal} \times S_{side\_seal} \qquad Rubbing\_J\_Bulb = 5.417 \frac{lb}{ft}$$

Hydrostatic Load Against the Side Seal Component::

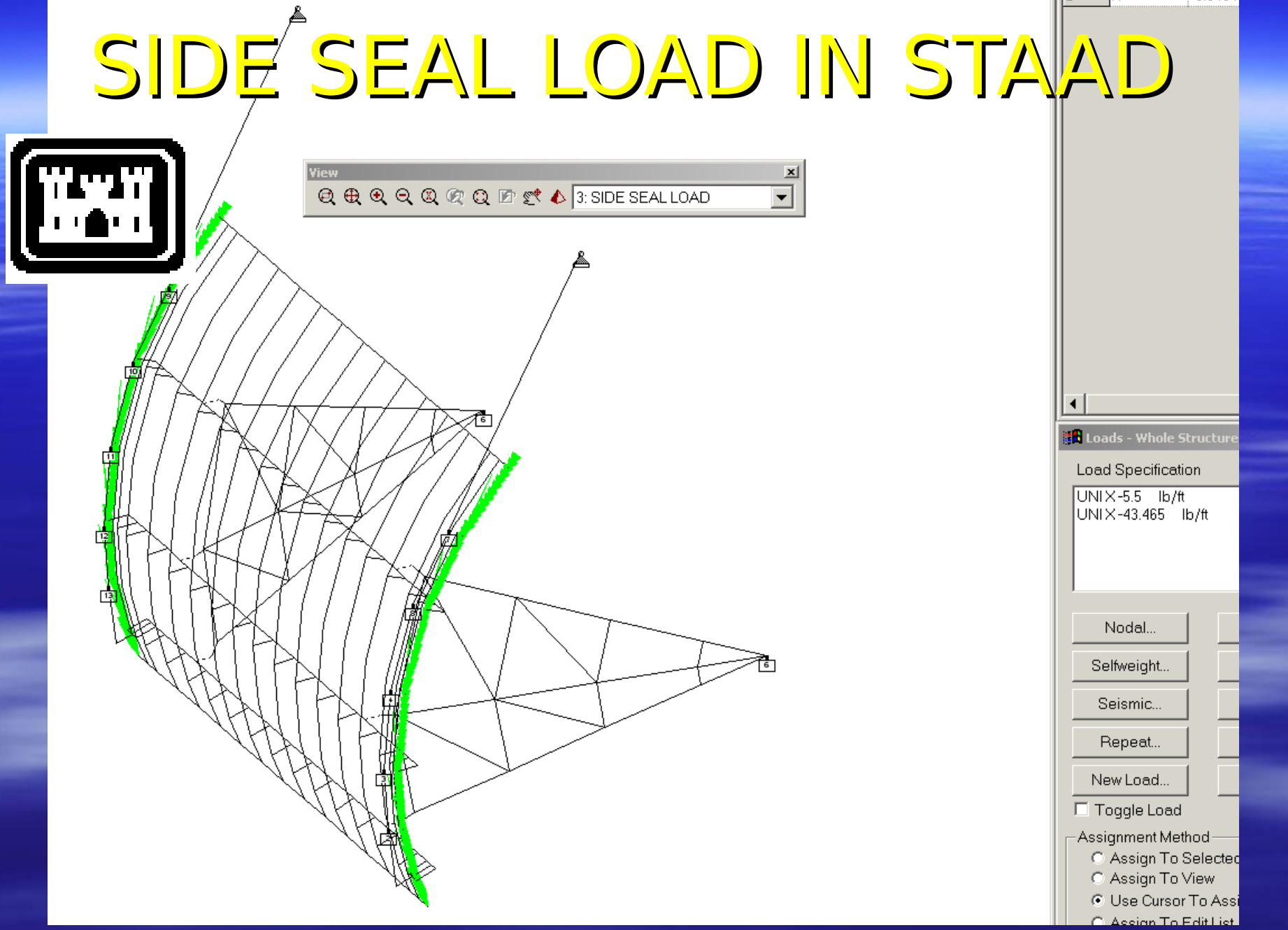
In the STAAD model this load is applied over the wet length of the side seal.

$$Hydostatic\_Force\_on\_J\_Bulb := \mu_{side\_seal} \times \gamma_{water} \times \frac{d_{side\_seal\_hydostatic\_pressure}}{2} \times \left(\frac{H_{pool}}{2} \right)$$

$$Hydostatic\_Force\_on\_J\_Bulb = 38.048 \frac{lb}{ft}$$

Total Force over wet length of side seal: $Rubbing\_J\_Bulb + Hydostatic\_Force\_on\_J\_Bulb = 43.465 \frac{lb}{ft}$

SIDE SEAL LOAD IN STAAD



TRUNNION FRICTION MOMENT

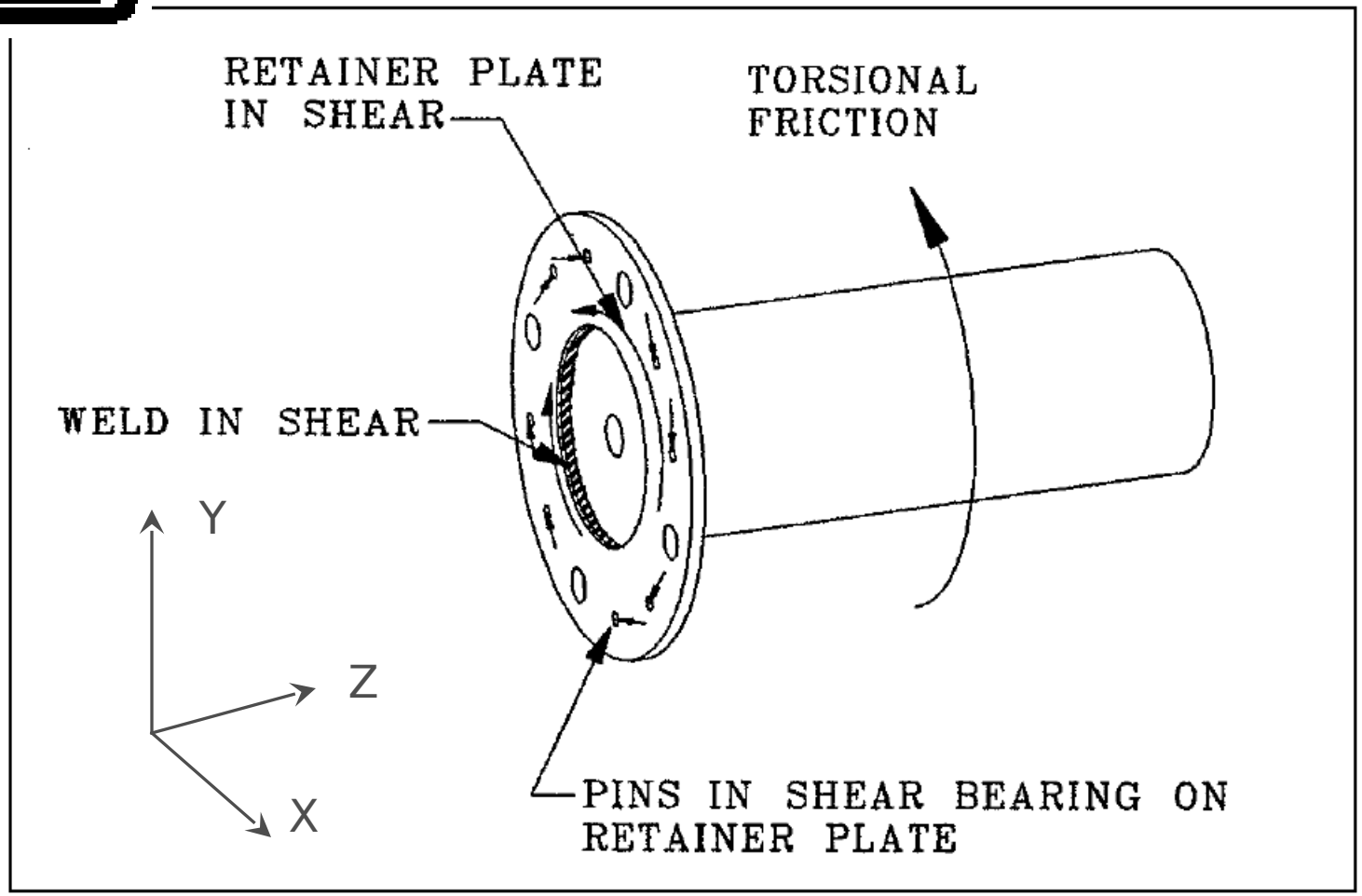
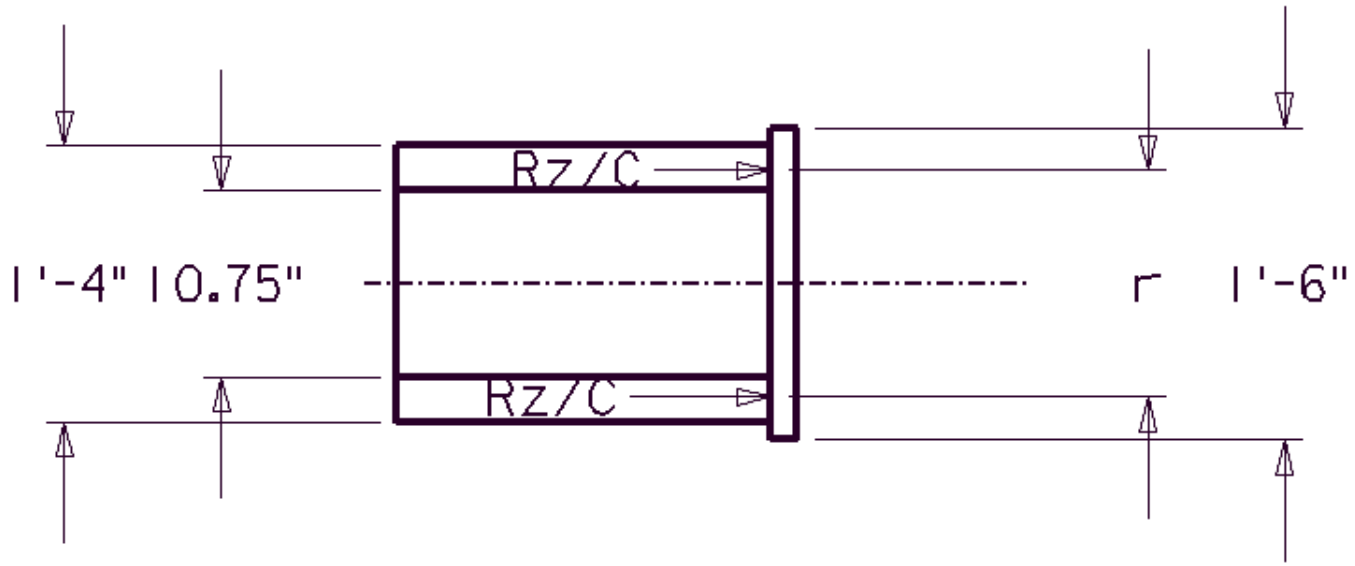


Figure 4-6. Generalized forces on trunnion pin and retainer plate

TRUNNION FRICTION MOMENT – THRUST COMPONENT

Thrust Bearing Friction:



Moment Arm:

$$r_{thrust} := \frac{\left(\frac{16}{2} - \frac{10.75}{2}\right)}{2} + \frac{10.75}{2}$$

$r_{thrust} = 6.688$

Figure based on Record Drawing 52.2/15

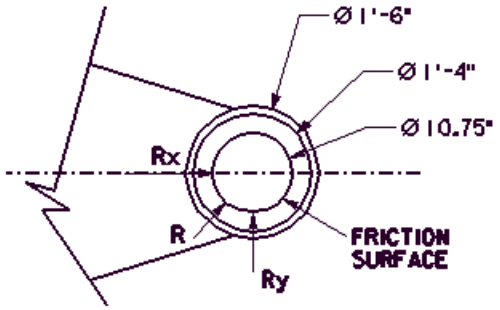
Strut Arm Factored Self weight Dead Load thrust Reaction for case @ 0 ft off the sill:

$R_z := 0.466kips$

< =This is the reaction at the the trunnion pin node.

TRUNNION FRICTION MOMENT – CIR COMPONENT

Circular Friction Moment:



Strut Arm Factored Self weight Dead Load Reaction for case @ 0 ft off the sill: $R_x := 2.908\,kips$ $R_y := 5.667\,kips$ Pin Diameter: $pin_{dia} := 10.0$

Note: When the gate is opened or closed the pin remains stationary. The bushing and the yoke move in circular motion. With the bushing surface rubbing against the lubricated pin surface.

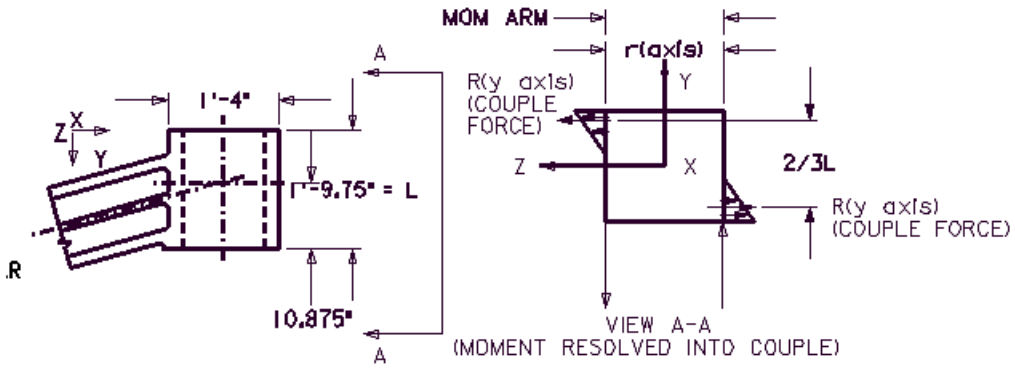
Obtain the Resultant force for the Reaction: $R_{resultant} := \left(\sqrt{R_x^{\,2} + R_y^{\,2}}\right)$ $R_{resultant} = 6.37\,kips$

$$M_{cir} := \left(\sqrt{R_x^{\,2} + R_y^{\,2}}\right) \times \frac{pin_{dia} \times in}{2} \times \mu$$

$M_{cir} = 0.796\,kips \times ft$

TRUNNION FRICTION MOMENT – ARM TORSION COMPONENT

Contribution to Trunnion Friction Moment from Reaction Moments at Trunnion Support:



X-Axis Moment:

All Moment Reactions about global X axis will contribute to circular moment:

Moment Arm: $r_{axis} := \frac{2}{3}(1ft + 9.75in)$ $r_{axis} = 14.5in$

Strut Arm Factored Self weight Dead Load Reaction for case @ 0 ft off the sill: $M_{x\_axis} := 0.083kips \times ft$

Normal Force Cause by x-axis moment: $R_{x\_axis} := \frac{M_{x\_axis}}{r_{axis}}$ $R_{x\_axis} = 0.069kips$

$M_{cir\_x\_axis} := R_{x\_axis} \times \left(\frac{pin_{dia} \times in}{2} \times \mu \right)$ $M_{cir\_x\_axis} = 0.009kips \times ft$

Load Case 2 Iteration 1 when gate is starting to lift from the sill:

$r_{axis} = 1.208\,ft$ $\quad r_{axis} := \frac{r_{axis}}{in}$ $\quad r_{axis} = 14.5$

$M_{T_0} :=$

Pin Dia	10	in	r_{axis}=	14.5	in					
Coef Fric	0.3									
r =	6.6875	in				**Friction Moment Components:**				
Load Case	R_x kips	R_y kips	R_z kips	M_x kips-ft	M_y kips-ft	X-axis circular moment	Y-axis circular moment	Thrust Moment kips-ft	Circular Moment kips-ft	Total Moment kips-ft
7	2.9	5.7	0.5	0.08	1.37	0.01	0.141	0.08		0.228
8	-412.6	-26.7	103.7	0.16	18.78	0.02	1.942	17.34		19.299
9	0.4	0.0	18.8	0.02	0.13	0.00	0.014	3.14		3.158
n/a	0.0	0.0	0.0	0.00	0.00	0.00	0.000	0.00		0.000
n/a	0.0	0.0	0.0	0.00	0.00	0.00	0.000	0.00		0.000
n/a	0.0	0.0	0.0	0.00	0.00	0.00	0.000	0.00		0.000
Total=	-409.3	-21.0							51.2	
								Total Moment M(T)=		**73.916**

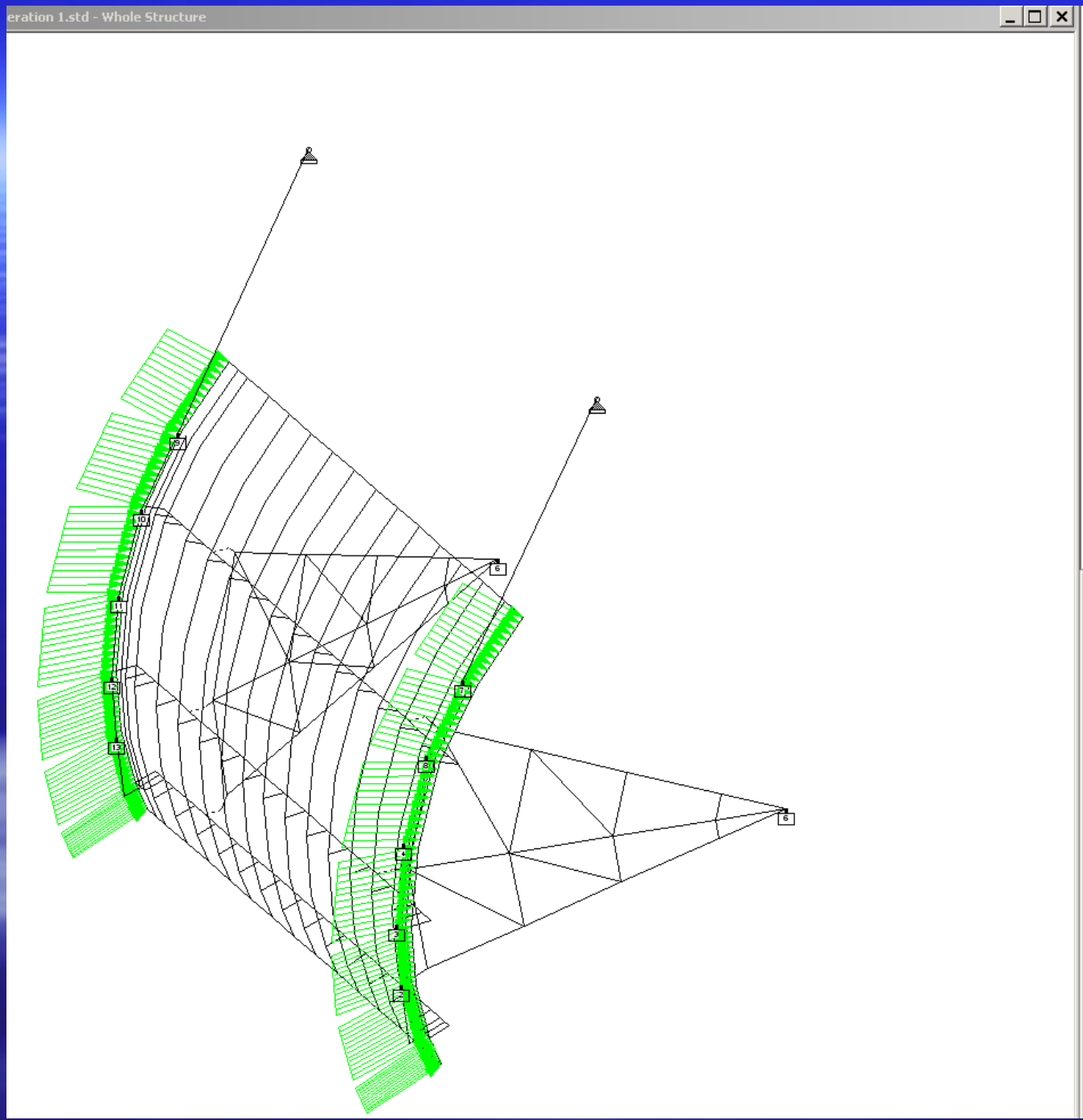
$(pin_{dia} \ \mu \ r_{thrust} \ r_{axis})$

$M_{T_0} = 73.916$

$M_T := M_T \times kips \times ft$ $\quad M_T^T = (73.916)\,kips \times ft$

$M_{Titer1} := M_T$

3. The uniform pressure due to the hoist rope ($W_T^T = (0.876)\,\frac{kips}{ft}$) and the total factored trunnion moment($M_T^T = (73.916)\,kips \times ft$) will be applied to a copy ("Alum Creek Load Case Iteration 1") of the model "Alum Creek Load Case Iteration 2" and steps 1 to 2 in above iteration method will continue until the applied R_Q and the attained R_Q are approximately equal. The uniform pressure will be applied to the exterior vertical rib of the skinplate assembly. The trunnion moment is applied to the trunnion pin node about the global Z axis.



Alum Creek Load Case Iteration 1.std - Load

Beam Uniform Force

Item	Direction	Force kips/ft	Start Distance in	Dis
1	Y	1	0	0
2	Y	-1	0	0

Loads - Whole Structure

Load Specification

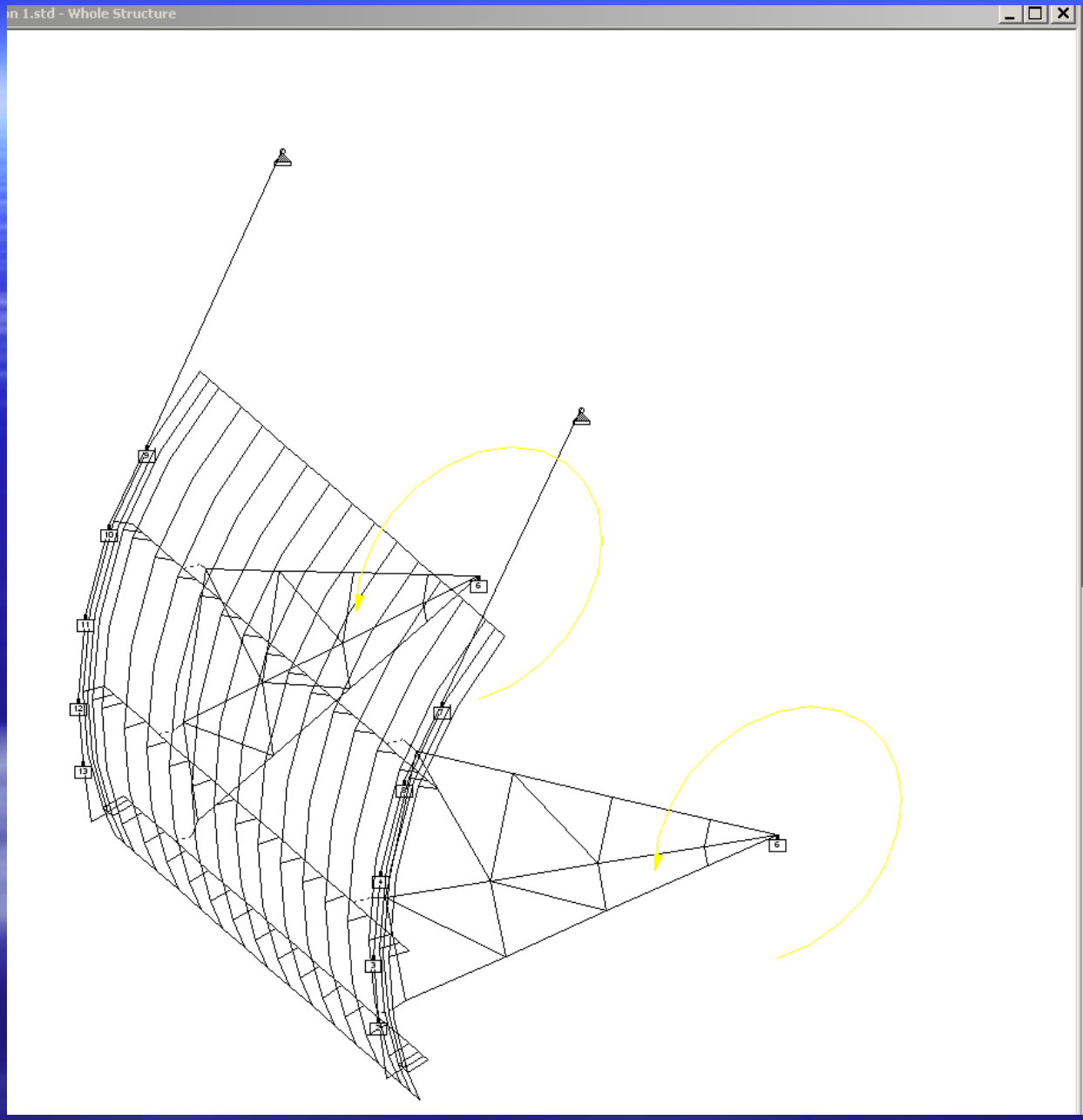
UNI Y 1000 lb/ft
UNI Y -1000 lb/ft

Nodal... Member...
Selfweight... Temp...
Seismic... Spectrum...
Repeat... Summary...
New Load... Remove...

Toggle Load

Assignment Method

- Assign To Selected Beams
- Assign To View
- (•) Use Cursor To Assign
- Assign To Edit List



Alum Creek Load Case Iteration 1.std - Load Values

Node Load

Item	Fz kip	Mx kip-ft	My kip-ft	Mz kip-ft
1	0	0	0	74
2				

Loads - Whole Structure

Load Specification

MZ 74000 lb

Nodal... Member... Plate...
Selfweight... Temp... Wind...
Seismic... Spectrum... Time History..
Repeat... Summary... Combine...
New Load... Remove... Moving...

Toggle Load

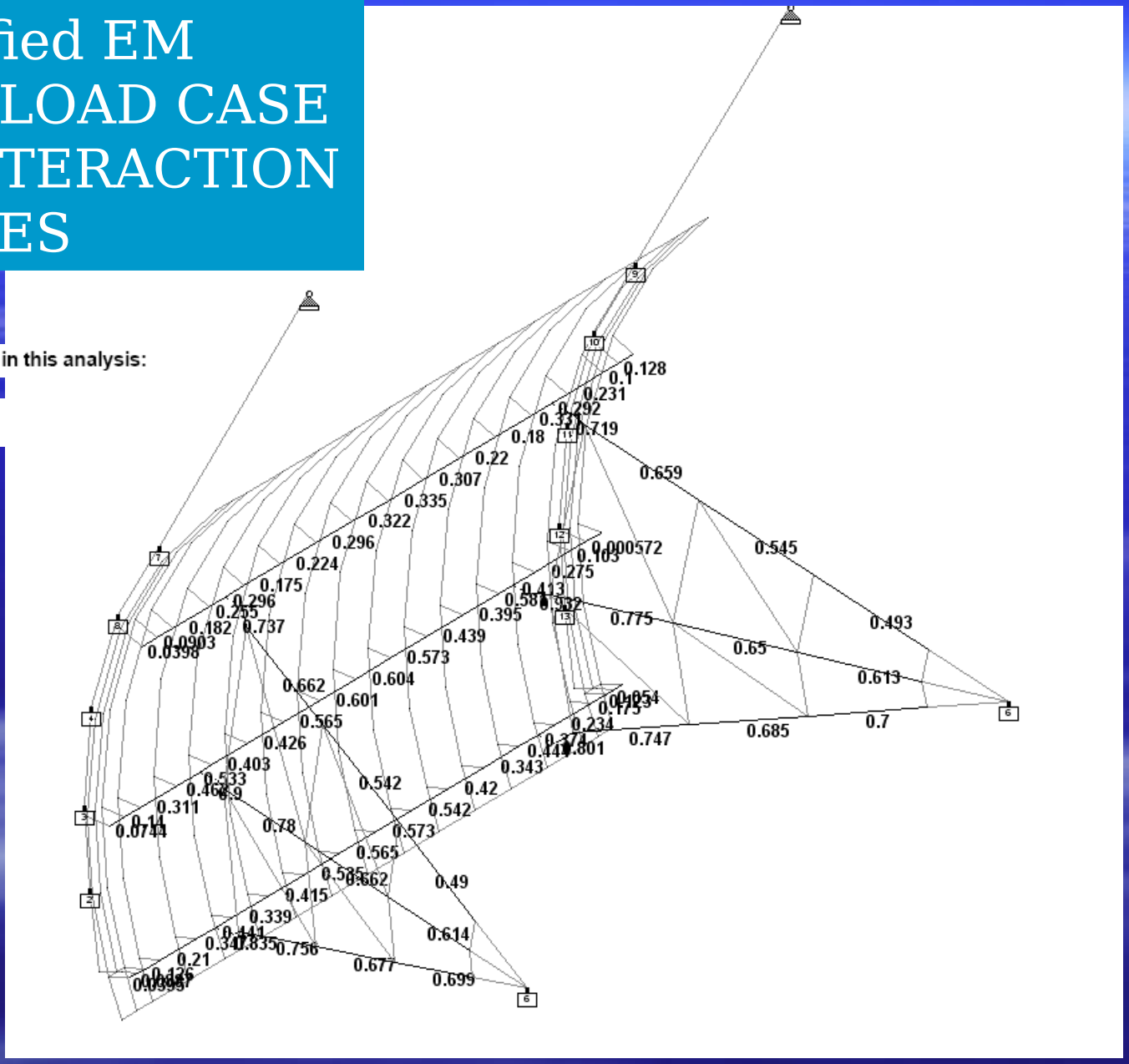
Assignment Method

- Assign To Selected Beams
- Assign To View
- Use Cursor To Assign

Modified EM 2702 LOAD CASE 1 - INTERACTION VALUES

EM Load Case 1 used in this analysis:

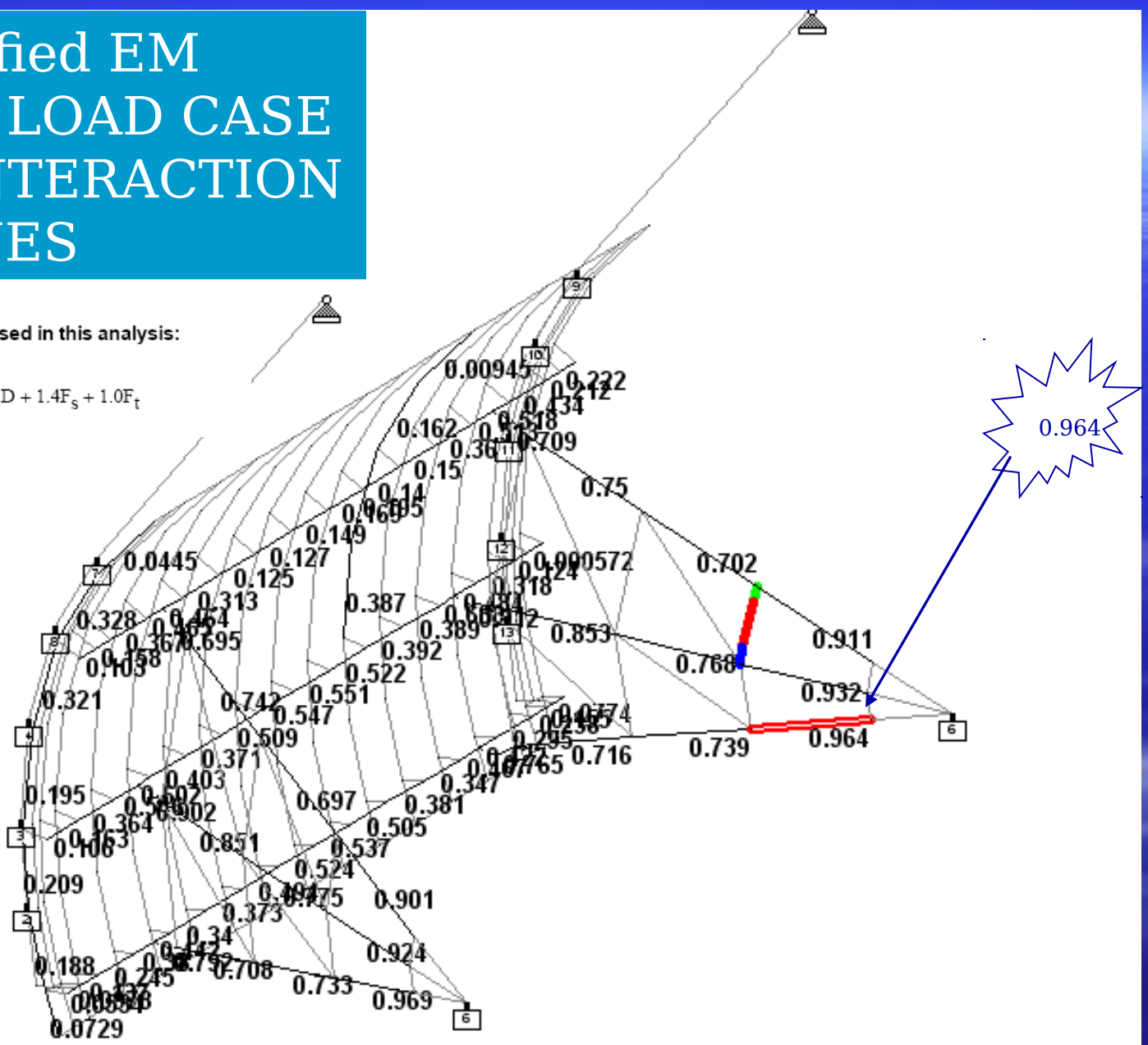
$1.4 \times H_1 + 1.2 \times D$



Modified EM 2702 LOAD CASE 2 - INTERACTION VALUES

EM Load Case 2 used in this analysis:

$1.4H_1 + 1.2D + 1.4F_s + 1.0F_t$

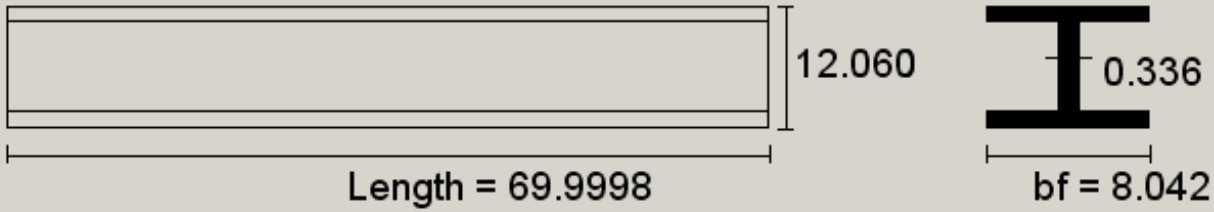


MEMBER WITH HIGHEST INTERACTION VALUE

Alum Creek Load 2 Case FINAL.std - Beam

Geometry | Property | Shear Bending | Deflection | Design Property | Steel Design

Beam no. = 174. Section: 12WF45



DESIGN STRENGTH (KIP,FT)

PNC	283.5	pnc	177.8
PNT	428.9	pnt	0
MNZ	170.6	mnz	7.6
MNY	51.1	mny	17.1

Critical load (KIP,INCH)

Load	6
Location	0
FX	177.813
MY	-205.463
MZ	-91.4901

Code	Result	Ratio	Critical	KLR
LRFD	PASS	0.964211	LRFD-H1-1A-C	67.0967

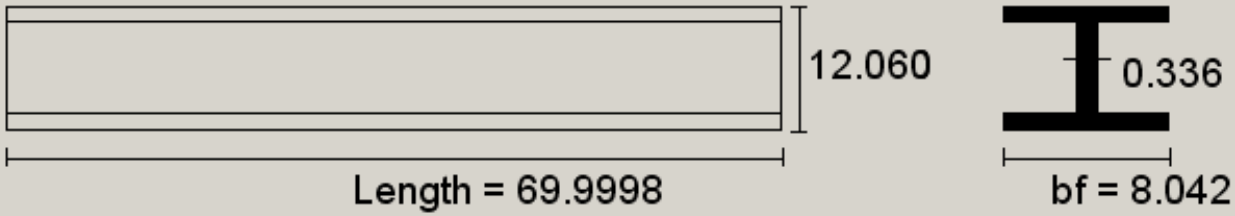
Print | Close

CONTROLLING MEMB W/O TRUNNION FRICTION MOMENT

Alum Creek Load 2 Case FINAL.std - Beam

Geometry | Property | Shear Bending | Deflection | Design Property | Steel Design

Beam no. = 174. Section: 12WF45



DESIGN STRENGTH (KIP,FT)

PNC	283.5	pnc	187.3
PNT	428.9	pnt	0
MNZ	170.6	mnz	4.2
MNY	51.1	mny	1

Critical load (KIP,INCH)

Load	6
Location	0
FX	187.352
MY	-13.0684
MZ	-51.4263

Code	Result	Ratio	Critical	KLR
LRFD	PASS	0.701981	LRFD-H1-1A-C	67.0967

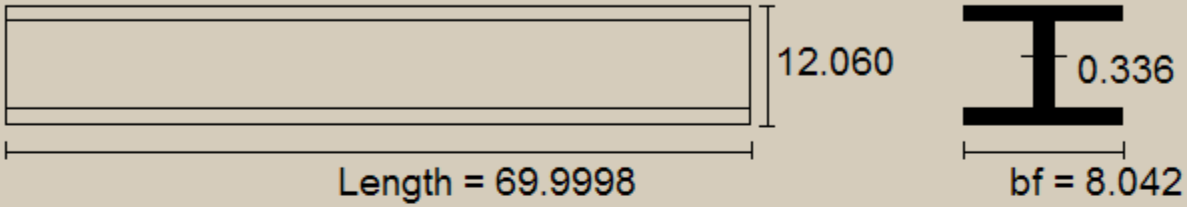
Print | Close

CONTROLLING MEMB W/O TRUNNION FRICTION MOMENT, AND SIDE SEAL

Alum Creek Load 2 Case FINAL No Moment No Side Seal - Beam

Geometry | Property | Shear Bending | Deflection | Design Property | Steel Design

Beam no. = 174. Section: 12WF45



DESIGN STRENGTH (KIP,FT)

PNC	283.5	pnc	183.2
PNT	428.9	pnt	0
MNZ	170.6	mnz	6.2
MNY	51.1	mny	1.1

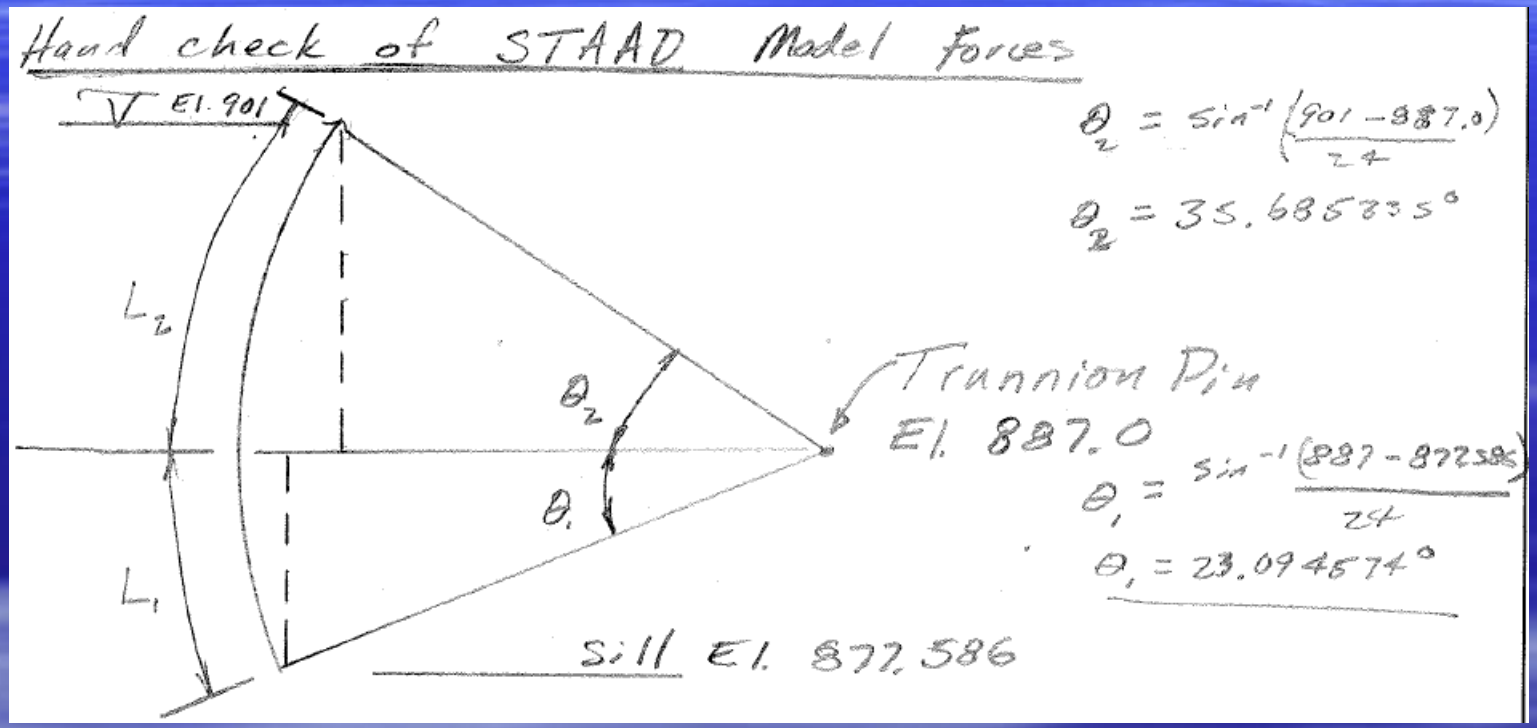
Critical load (KIP,INCH)

Load	10
Location	0
FX	183.234
MY	-13.5631
MZ	-75.3374

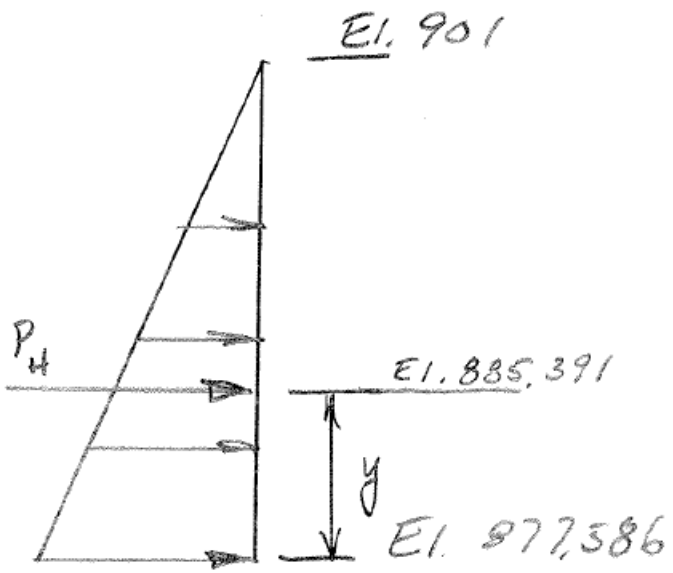
Code	Result	Ratio	Critical	KLR
LRFD	PASS	0.698544	LRFD-H1-1A-C	67.0967

Print | Close

HAND CHECK OF MODEL- TOM WRIGHT



HAND CHECK OF MODEL- TOM WRIGHT



Horizontal component of Hydrostatic load;

$$P_H = \frac{1}{2}\gamma_w (901 - 877.586)^2$$

$$P_H = \frac{1}{2}(62.4)(901 - 877.586)^2$$

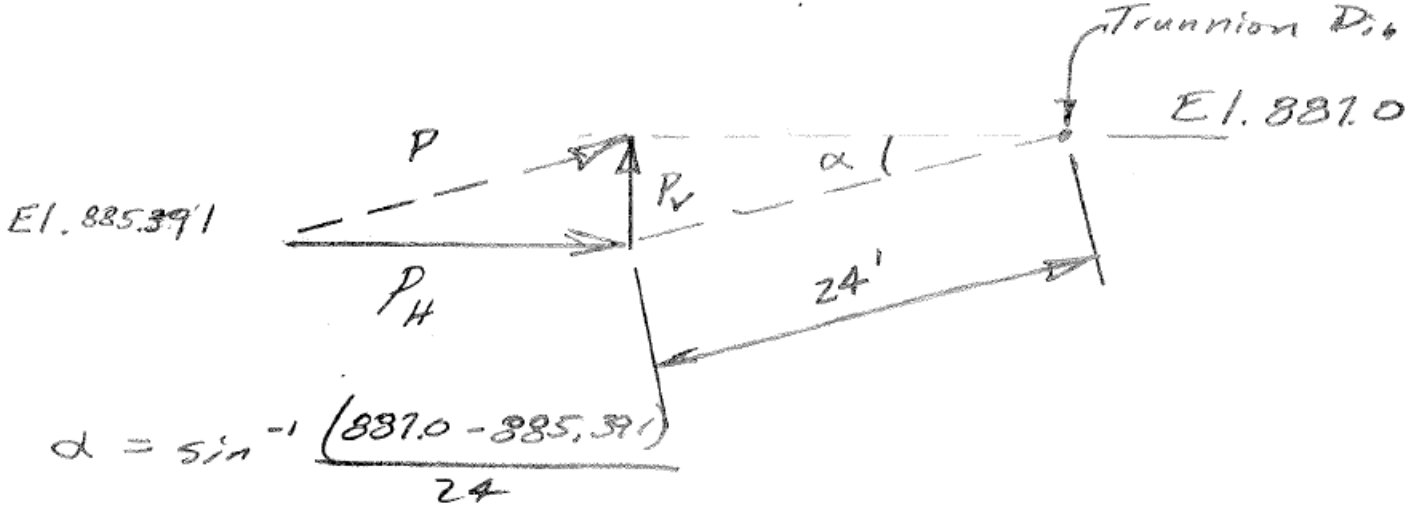
$$P_H = 17,104 \text{ lb/ft}.$$

$$y = \frac{1}{3}(901 - 877.586)$$

$$y = 7.80467 \text{ ft}$$

HAND CHECK OF MODEL- TOM WRIGHT

Resultant of hydrostatic force must pass through the center of the skin plate radius ⇒ trunnion pin



$$\alpha = \sin^{-1}\left(\frac{887.0 - 885.391}{24}\right)$$

$$\alpha = 3.8448854^\circ$$

$$\tan\alpha = \frac{P_V}{P_H}$$

$$P_V = P_H \tan\alpha = (17{,}104)(\tan 3.8448854^\circ)$$

$$P_V = 1149.5 \text{ lb./ft.}$$

HAND CHECK OF MODEL- TOM WRIGHT

$R_{TOTAL} = \frac{1}{2}(34)(17,142.6)$

$R_{TOTAL} = 291,424$ lb / trunnion

$R_x = (17,104)\left(\frac{34}{2}\right) = 290.8$ kips

$R_y = (1.1495)\left(\frac{34}{2}\right) = 19.5$ kips

Load Factor = 1.4

$R_{ux} = 407.12$ kips

$R_{uy} = 27.3$ kips

Shahir's Nos:

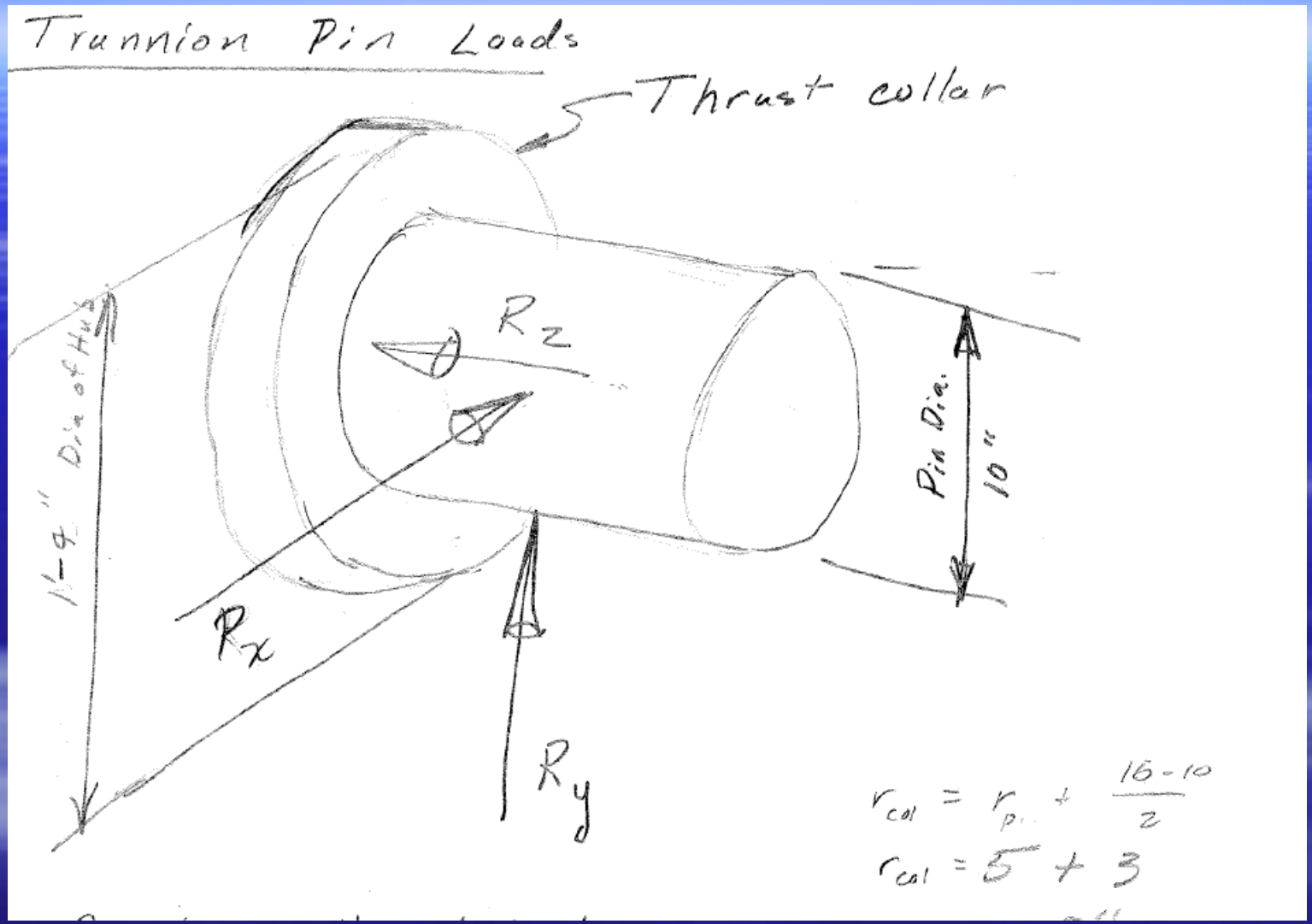
$R_{ux} = 417.6$ k → 1.3% diff

$R_{uy} = 26.7$ k → 2.1% diff

OK

MRK FORM [illegible]222

HAND CHECK OF MODEL- TOM WRIGHT



HAND CHECK OF MODEL- TOM WRIGHT